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ABSTRACT

Project AIMS (Activities to Integrate Mathematics and Science) has as its purpose the integration of subject matter in grades K-9 on the premise that such integration enriches and makes learning meaningful and holistic. In fact, extensive field testing of the curriculum materials produced by AIMS has confirmed that integration produces the following beneficial results: (1) mathematics becomes more meaningful, hence more useful; (2) science is increasingly studied and understood, with a significant economy of time; (3) there is improved quality of learning and retention; and (4) there is a dramatic increase in students' motivation and involvement. This teaching guide to surface properties of fluids for grades 4-9 contains 23 lessons., each with a instructions page with lists of materials, objectives and procedures, and reproducible worksheets for students. Topics include: (1) "Beginning Experiences"; (2) "Minimum Surfaces"; (3) "More Physical Properties"; (4) "Bubble Life"; and (5) "Bubble Applications." Also included is a glossary, a checklist of science processes and math skills, a list of children's literature which may be used to extend these lessons, a list of materials for the unit, basic soap solution recipes, bubble challenge ideas, a list of "big ideas," a selective bibliography of 23 references, and information on the AIMS project. (CW)

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Project AIMS
Grades 4-9

Liquid Soap
Soap
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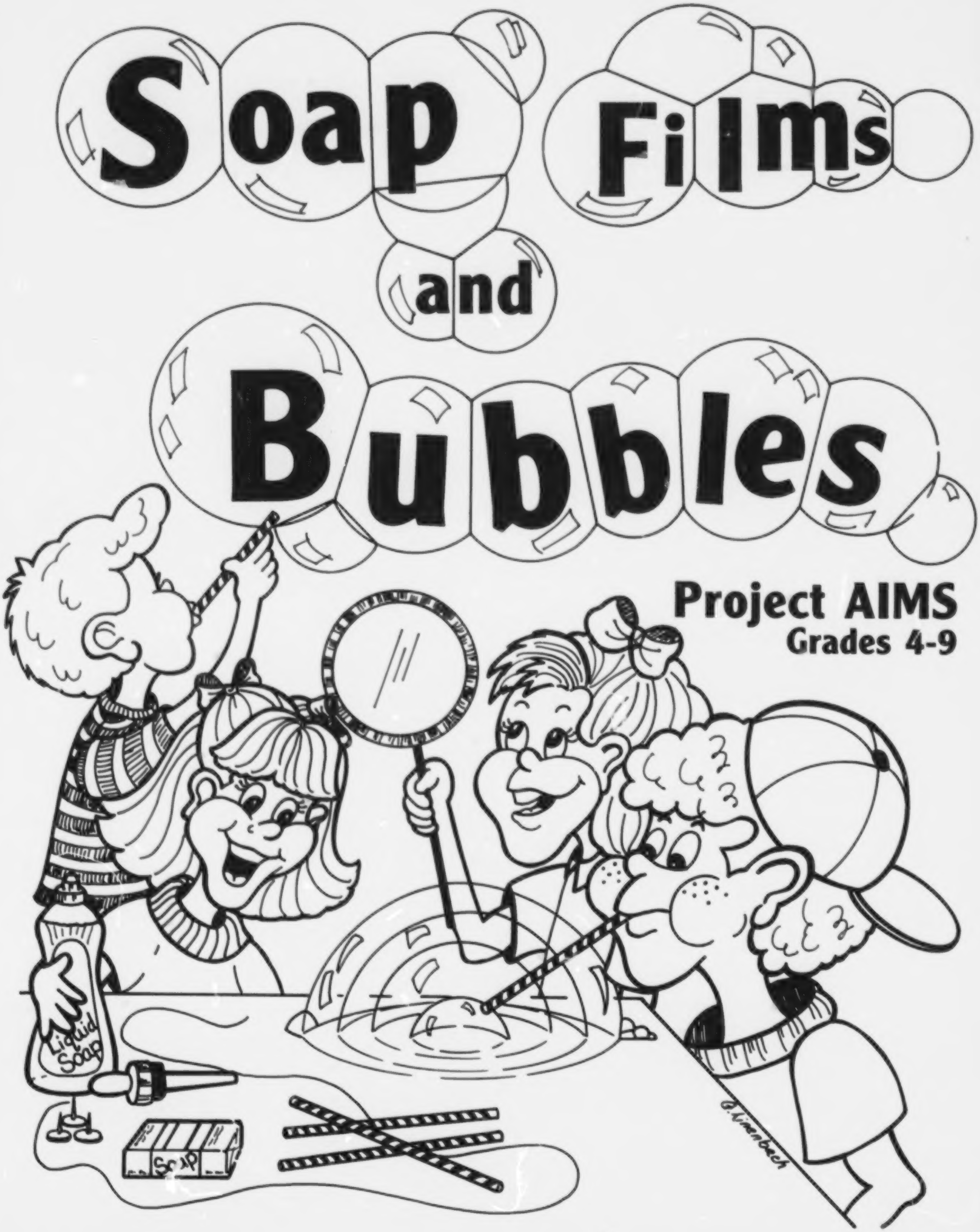
Soap Films and Bubbles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Soap
B. Kimenbach

Project AIMS

Grades 4-9

Soap Films and Bubbles

by

Ann Wiebe
Kings Canyon Unified School District
Reedley, California

Illustrations

by

Brenda Howsepian

Editor

Dave Youngs
Project Director
Fresno Pacific College

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Project AIMS

Project AIMS has as its purpose the integration of subject matter in K-9. Such integration enriches and makes learning meaningful and holistic. Project AIMS began as a program to integrate mathematics and science, but has since developed to also include language arts, social studies, and other disciplines. The acronym "AIMS" stands for "activities to integrate mathematics and science."

Project AIMS is a continuing, non-profit project of Fresno Pacific College. It had its inception in a National Science Foundation funded program to train teachers in the integration of mathematics and science. This quickly created the necessity to write instructional materials incorporating this concept. Despite the fact that thoughtful educators have long recommended this approach, very little appropriate material was available.

Currently, Project AIMS is funded solely through the sale of this developing series of books. All net proceeds from their sale flow into a trust fund administered by Fresno Pacific College. The use of this fund is restricted to the support of continued research and development, partial scholarships for classroom teachers who participate in the writing and field testing teams, and the publication of the books.

The rationale for this integrative thrust lies in the fact that science, mathematics, language arts, social studies, etc., are integrally interwoven in the real world outside the classroom, from which it follows that they should be similarly treated in the classroom if we are to prepare our students for life in that world. Teachers who have used Project AIMS lessons give enthusiastic endorsement to the effectiveness of this approach.

Science encompasses the art of questioning, investigating, hypothesizing, and discovering. Mathematics is the language that provides clarity, objectivity, and understanding. The language arts provide us with powerful tools of communication. Many of the major contemporary issues involve societal issues stemming from advancements in science. It is time, therefore, that all of us in the teaching profession take seriously using a more holistic mode of transmitting knowledge to students. It is this that motivates all of us who are involved in creating or using the integrative materials of Project AIMS. We invite you to join us in this effort.

Extensive field testing of these materials confirms the following beneficial results.

1. Mathematics becomes more meaningful, hence more useful, when it is applied to situations that interest students.
2. The extent to which science is studied and understood is increased, with a significant economy of time resulting from the integration of two or more disciplines.
3. There is improved quality of learning and retention, supporting the thesis that learning which is meaningful and relevant is more effective.
4. Motivation and involvement are increased dramatically as students investigate real world situations and participate actively in the process.

We invite you to become part of this classroom teacher movement by using an integrated approach and by sharing any suggestions you may have or investigations you would recommend. Project AIMS welcomes you!

Project AIMS Publications

GRADES 5–9 SERIES

Math + Science, A Solution
The Sky's the Limit
From Head to Toe
Fun With Foods
Floaters and Sinkers
Down to Earth
Our Wonderful World
Pieces and Patterns, A Patchwork in Math and Science
Out of This World, Book A
Soap Films and Bubbles (4-9)

GRADES K–4 SERIES

Fall Into Math and Science
Cáete de gusto hacia el OTOÑO con las MATHEMÁTICAS y CIENCIAS
Glide Into Winter With Math and Science
Patine Al INVIERNO con MATEMÁTICAS y CIENCIAS
Spring Into Math and Science
Brinca de alegria hacia la PRIMAVERA con las MATEMÁTICAS y CIENCIAS
Seasoning Math and Science, Book A (Fall and Winter)
Seasoning Math and Science, Book B (Spring and Summer)
Jawbreakers and Heartthumpers
Hardhatting in a Geo-World
Popping With Power
Overhead and Underfoot

GRADES K–6

Primarily Bears, Book 1
Water Precious Water, Book A
Critters

FOR FURTHER INFORMATION WRITE TO:

AIMS Education Foundation
P. O. Box 7766
5629 E. Westover Street
Fresno, California 93747

I HEAR, AND I FORGET
I SEE, AND I REMEMBER
I DO, AND I UNDERSTAND

–Chinese Proverb

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Whet Your Appetite		✓																
It's a Touchy Subject									✓									
Taking Shape										✓								
Bubble Clusters					✓					✓	✓							
Water Rings		✓																
Macro Molecules											✓	✓						
Pulling Strings		✓					✓	✓				✓	✓	✓				
Stretching Out		✓		✓		✓								✓	✓			
Arching Links											✓							
Thumbtack Sandwich I		✓														✓		
Thumbtack Sandwich II		✓											✓			✓		
A Fork in the Road					✓		✓			✓		✓					✓	
Reflections on Geo-Panes					✓		✓			✓		✓						
Under Pressure					✓													✓
Bubbles Aloft																		
Riding on Air	✓																	
Liquid Rainbows													✓					
Soap Cookbook						✓												
What's the Best Solution?			✓	✓														
Don't Burst My Bubble			✓	✓									✓					
Swell Hemispheres	✓			✓									✓					

Science Processes

	Observing/Classifying	Measuring/Comparing	Collecting/Recording Data	Predicting/Inferring	Identifying/Controlling Variables	Making/Testing Hypotheses	Applying/Generalizing	Interpreting Data
Whet Your Appetite	✓							
It's a Touchy Subject	✓	✓	✓		✓	✓	✓	✓
Taking Shape	✓	✓	✓				✓	
Bubble Clusters	✓		✓				✓	
Water Rings	✓	✓	✓			✓	✓	
Macro Molecules		✓					✓	
Pulling Strings	✓	✓	✓	✓				✓
Stretching Out	✓	✓	✓	✓			✓	
Arching Links	✓	✓	✓		✓		✓	✓
Thumbtack Sandwich I	✓	✓	✓	✓				
Thumbtack Sandwich II	✓	✓	✓	✓				
A Fork in the Road	✓	✓	✓	✓			✓	✓
Reflections on Geo-Panes	✓		✓	✓			✓	✓
Under Pressure	✓	✓	✓			✓	✓	✓
Bubbles Aloft	✓		✓				✓	
Riding on Air	✓	✓	✓	✓			✓	✓
Liquid Rainbows	✓	✓	✓	✓			✓	✓
Soap Cookbook		✓						
What's the Best Solution?			✓		✓	✓	✓	✓
Don't Burst My Bubble	✓		✓	✓	✓		✓	✓
Swell Hemispheres		✓	✓	✓				

Extend AIMS Lessons with Children's Literature

During summer AIMS workshops Debby Deal and Gale Kahn encouraged teachers to submit the names of favorite books that related to various AIMS activities. Below are two such lists, one for primary grades and the other for middle grades. We encourage our readers to help us expand these lists. AIMS places heavy emphasis on the integration of learning and is pleased to print the following information.

PRIMARY

Lesson Topic	Book Title	Author
Feet/Shoes	Foot Book	Dr. Seuss
	The Aminal	Bulian
	The Very Worst Monster	Hutchins
	Shoes	Winthrop
	Funny Feet	Weiss
Fruits/Vegetables/Health	The Very Hungry Caterpillar	Carle
	Gregory, The Terrible Eater	Sharmat
Seeds/Leaves	Reason for a Flower	Heller
	Fall of Freddie Leaf	Buscaglia
	Pumpkin, Pumpkin	Titherington
Detective	Detective Whooo	Panek
Ghosts	Georgie The Ghost Book	Bright
	The Haunting of Grade 3	???
	Cranberry Halloween	Devlin
	Great Halloween Scare	???
	The Ghost Eye Tree	Martin
	Little Old Lady Who Wasn't Afraid of Anything	Williams
Rainbow	Plant a Rainbow	Ehlert
	Little Blue and Little Yellow	Lionni
Flower	Plant a Rainbow	Ehlert
	The Reason for a Flower	Heller
Start of School	The Blanket Had To Go	Evans
Fish	Fish Out of Water	???
	Yeh-Shen	Louie
Bears	Teddy Bear Picnic	Kennedy
	Corduroy	Freeman
	When a Bear Bakes a Cake	Tomkins
	Ten Bears in My Bed	Mack
	Big Bad Bruce	Peet
	Teddy on Time	Pellowski
Eggs	Are You My Mother?	Eastman
	Chickens Aren't the Only Ones	Heller
	Seven Eggs	McKenna
	What's Hatching Out of That Egg	Lauber
Snails	The Biggest House in the World	Lionni
	Snails Spell	Ryder
Dinosaurs	Weekly Reader — Dinosaur Kit 4343 Equity Dr., Columbus, OH 43228 Pat Perea Materials, S/S Pub. Co. 3550 Durock Rd. Shingle Springs, CA 95682 (916) 677-1545	
	Dinosaur Pop-up Book	Barlowe
	Patrick's Dinosaur	Carrick
Popcorn	The Popcorn Book	de Paola
	Popcorn	Asch
Measurement	Inch By Inch	Lionni
	How Much Is A Million?	Schwartz
Animals	Annie and Wild Animals	Brett
	The Big Snow	Hader
	Dear Zoo	Campbell
	Animal Fact/Animal Fable	Simon
	Animals Born Live and Well	Heller
Camouflage	How to Hide a Butterfly	Heller
	Where's Waldo	Handford
	The Trek	Jonas
	Animals Who Change Their Color	Almand
Pet Rock	Everybody Needs a Rock	Baylor
Jelly Beans	The Jelly Bean Contest	???
Eyes	People	Spier
	Illusions	Troll Assoc.
Art	Make a World	Emberley
Hermit Crabs	Does Anyone Know Where a Hermit Crab Goes?	???
Space/Sun	The Sun Our Nearest Star	Branley
	What Makes Day and Night	Branley
	Done in the Sun	Hillerman
Weather	Snow is Falling	Branley
	Sunshine Makes the Seasons	Branley
	Flash, Crash, Rumble and Roll	Branley
	Cloudy with a Chance of Meatballs	Barrett
Shadows	Shadow Chaser	Cosgrove
Miscellaneous	Do You Know?	Ford
	The King Who Rained	Gwynne
	The Jolly Postman	Ahlberg
Creature Features	Where the Wild Things Are	Sendak
Fun Fruits	Huge Harold	Peet
	Hubert's Hair Raising Adventure	Peet
Bubbles	Unbelievable Bubble Book	Cassidy
Apples	Ten Apples up on Top	Dr. Seuss
Observation	Anamalia	Base
	Wilfred Gordon McDonald Partridge	Fox
	Do Not Open	Turkle
Corn	Corn is Maize	Aliki
Moon	Moonbeam on a Cat's Ear	Gay
Questions	How Come?	Richards
Nature	King's Flower	Anno
Body Parts	Here Are My Hands	Martin, Jr.
Insects	Squiggly Wiggly's Surprise	Shapiro
	How Many Bugs in a Box	Carter
Senses	Series. . . Sight, Hearing, Touch, Smell, Taste	Ruis
Self Esteem	Quick as a Cricket	Wood
Birds	Owl Moon	Yolen
Numbers	Anno's Counting Book	Anno
Water Fun	King Bidgood's in the Bathtub	Wood
Magnets	Mickey's Magnets	Cranley
Serial Ordering	Where in the World is Henry?	Balian
Asking Questions	Owly	Thaler
Heat, Water	Snowy Day	Keats
Earth/Physical Science	Pecos Bill	Kellogg
Songbook	All Year Songbook	Scholastic
Plants	Seedling Child	Bornstein
Critters	Fables	Lobel
	Aster Ardvarks Alphabet Adventures	Kellogg
	Barn Dance	Martin
	Q is for Duck an Alphabet Guessing Game	Elting
	Silkworms	Johnson
	Very Hungry Caterpillar	Carle
	Predator Prey Puppets	Mah
	Beastly Neighbors	Rights
Foods	Alligator Arrived with Apples	???
	A Potluck Alphabet Feast	???
	Cresent Dragonwagon	???
Spiders, Lettuce	Lady and the Spider	McNulty

MIDDLE GRADES

Lesson Topic	Book Title	Author
Rocks	Everybody Needs a Rock	Baylor
	Syllvester and the Magic Pebble	Steig
Measurement	How Tall Was Milton	Lowery
Insects	101 Bug Jokes	Eisenberg
General Information	What?	Reece
	Random House Book of Poetry	Prelutsky
Camouflage	How to Hide. . . Series	Heller
Seasons	Frederick	Lionni
Animals	Animals Born Alive and Well	Heller
Ecology	Introducing Ecology: Nature at Work	British Museum
Music	Peter and the Wolf	
Senses	Look Again	Hoban
Fractions	Gator Pie	Mathews
Boats	Paddle to the Sea	???
	Three Days on a River in a Red Canoe	Williams
Geology	Ming Lo Moves the Mountain	Lobel
Classification	Bruno Brontosaurus	Rubel
Weather	Cloud Book	de Paola
Bears	Baby Bears	National Geographic
	Happy Birthday Moon!	Asch
	Corduroy	Freeman
	Who Wants an Old Teddy Bear?	Hofmann
	Teddy Roosevelt and his Teddy	???
Popcorn	The Popcorn Book	de Paola
Numbers	How Much Is a Million?	Schwartz
Multiplication	Bunches & Bunches of Bunnies	Mathews
Language	The Jolly Postman	Ahlberg
Money	Alexander Who Used to be Rich Last Sunday	Viorst
Mirrors	The Mirrorstone	Palin
	If You Give a Mouse a Cookie	Numeroff

Mathematics: A Way of Thinking
Center for Innovation in Education
19225 Vinegar Lane
Saratoga, CA 95070

Family Math
Univ. of California, Berkeley
Lawrence Hall of Science
Berkeley, CA 94720

Standard and Expanded AIMS Duplication Programs

It is the goal of the AIMS Education Foundation to make its materials and programs available to schools and educators at reasonable cost consistent with the maintenance of high standards of quality.

The support for continued research, development, field-testing, and publication of AIMS materials is dependent entirely on the revenue produced from the sales of books, posters, the AIMS Newsletter, and other publications of the Foundation.

It is, therefore, of utmost importance that all educators and educational agencies carefully observe the generous privileges and applicable restrictions for duplication.

Two broad types of duplication privileges are offered: standard and expanded. Within the expanded duplication program Class I and Class II contracts are available. Each of these is defined in detail below.

Standard Duplication Privileges

A school or individual purchasing any AIMS publication is granted the right to make up to 200 copies of any of the materials therein for use by teachers at that school site.

Workshop leaders may make up to 200 copies in the same manner as schools. Teachers receiving copies from workshop leaders may duplicate no more than 35 copies of student pages received in a workshop or enough to use the lessons one time with one class. Any further duplication without the purchase of the materials is strictly forbidden.

All educators conducting AIMS workshops are expected to explain the Model of Mathematics and Model of Learning and consistently refer to it as activities are presented since these Models are the basis on which the AIMS program rests. Such understanding is essential to achieve the highest possible benefit from AIMS.

If an educational agency publishes a newsletter or similar publications for distribution to multiple sites, no more than 200 copies of any AIMS materials included therein may be made without written permission from the AIMS Education Foundation. Further, such multiple-site newsletters may duplicate no more than one science activity and one mathematics activity from any one issue of the AIMS Newsletter or book.

Whenever AIMS materials are duplicated in any form the AIMS Education Foundation copyright must appear. In the case of newsletters or similar publications information regarding the availability of AIMS publications and the fact that they may be ordered from the Foundation must be noted.

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The AIMS Education Foundation has approved programs whereby schools, school districts, and other non-profit educational agencies may purchase additional duplication rights. These programs are particularly appropriate for districts who wish to publish AIMS materials in a central office for district-wide use or to publish more than the 200-copy limit which comes with the purchase of a book.

Two classes of rights are available:

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Address all correspondence and purchase order to:

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AIMS Newsletter Subscription Information

Each issue of the AIMS Newsletter contains a wealth of resources consisting of new AIMS integrated mathematics/ science investigations, simple science experiments, and problem solving mathematics activities.

The AIMS Newsletter is published monthly, August through May. Subscriptions are on an annual basis only. A subscription entered at any time will receive the 10 issues for that year beginning with the previous August issue. This format is used since many of the articles in an annual volume are interrelated and all need to be available for maximum benefit.

The average issue of an AIMS Newsletter contains four or more new AIMS investigations, at least one each at the K-1, 2-4, and 5-9 grade levels; one 8.5 x 11 inch blackline master poster describing a simple science experiment; two 8.5 x 11 inch blackline master posters displaying problem solving situations; information about developments in the AIMS program, workshops, courses, and other activities; feature articles of lasting value dealing with science instruction, problem solving in mathematics, etc.; a description of how a school, district, or state is implementing AIMS in a systemmatic manner; activities by members of the AIMS National Leadership Network and the writing teams; a thorough preview of all new AIMS and SETUP publications; information about conference presentations by the program directors of AIMS where participants can meet with them personally; and a periodic listing of all AIMS publications.

The problem solving poster series in the Newsletter is accompanied by a thorough analysis of problem solving approaches appropriate to each situation. This analysis serves as an aid to classroom teachers who wish to enhance their own knowledge of problem solving and help students acquire an inventory of problem solving skills. Authored by Wilbert Reimer and Arthur Wiebe, both of whom studied extensively under Dr. George Polya at Stanford University, both series reflect his influence.

The ten issues in the annual volume contain forty or more new AIMS investigations, ten science posters, and twenty problem solving challenges, plus numerous articles dealing with the teaching of "hands-on" science, evaluating higher order thinking skills and student progress in mastering process skills, and other enriching resources.

Since duplication rights for one school site are granted for all materials published in the Newsletter, it is highly cost effective for a school to enter a subscription and build a library for the use of all of its teachers.

The annual subscription price is $22.50. Volumes I and II are still available.

AIMS Newsletter Subscription

Subscriptions are accepted on an annual basis only. Subscriptions entered at any time during the year receive all issues of that year, August – May.

Please indicate quantity:

____ Volume I issues 1986-87
____ Volume II issues 1987-88
____ Volume III issues 1988-89
____ Volume IV subscription 1989-90
____ Volume V subscription 1990-91

Order any one volume for $22.50, each additional volume on this order is $20.00.

Subscription Information:

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Address: ____________________
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Make payment to:

AIMS Education Foundation
P.O. Box 7766
Fresno, CA 93747

x

AIMS Education Foundation Programs

The AIMS Education Foundation sponsors a variety of programs and services.
Write for additional current information about any of these:

AIMS National Leadership Program in Math/Science

The Leadership program provides training in science and mathematics for teachers in grades K-9 using the AIMS integrated mathematics/science approach. Intensive training is provided in the physical, biological, earth science, and mathematics topics and the science process skills.

Participants receive 300 hours of instruction in a two-summer sequence. During each academic year following, the participant provides a minimum of 40 hours of instruction to teachers in the local district or region.

Upon successful completion of these requirements, trainers qualify to become members of the AIMS National Leadership Network, conduct AIMS workshops, teach AIMS in-service courses for college credit, and serve as AIMS consultants to help meet the widespread demand for such services.

The program the first summer consists of the AIMS National Leadership Institute (three weeks in July). The second summer schedule consists of the Festival of Mathematics (two weeks in late June). Write for current information.

AIMS One-Week Summer Workshops

The AIMS Education Foundation will offer 50 or more one-week AIMS Workshops nationally each year. The sites are selected from applicant educational organizations who wish to serve as the hosts. Each workshop is of five days duration and includes 30 hours of instruction, primarily hands-on, in AIMS. Most are offered in three grade level sections, generally K-1, 2-4, and 5-9. Participants receive $50+ in materials.

Host agencies agree to provide appropriate classroom space and related services at no cost to the Foundation and to cooperate in the promotion of the workshop. This is the only cost to the host agency. The AIMS Education Foundation pays all instructional costs; the housing, meals, and travel of instructors; and workshop materials and supplies. During 1990 the cost per participant is $195. Instructors are members of AIMS National Leadership Network.

Educational agencies interested in making application to host a workshop should request current information and application forms.

AIMS On-Campus Workshops

Each summer AIMS offers one-week AIMS Workshops at Fresno Pacific College in Fresno, California. The program directors of the AIMS Education Foundation and key members of the AIMS National Leadership Network serve as instructors. Two semester units of graduate credit are available.

Science Festival and Festival of Mathematics

Fresno Pacific College offers outstanding programs each summer: the Science Festival and the Festival of Mathematics. Guest faculty include some of the nation's most highly regarded mathematics and science educators. Provision is made for all grade levels from kindergarten through high school.

These two Festivals offer a unique educational experience and annually draw a total enrollment of more than 600 teachers from across the nation.

"A Day with AIMS"

"A Day with AIMS" offers an intensive one- and two-day AIMS workshops to introduce teachers to AIMS and its philosophy. Participants become familiar with the basic principles incorporated into AIMS; engage in an extensive series of hands-on AIMS investigations; and discuss classroom management and methods for integrating AIMS into the curriculum. Participants receive more than $30 worth of materials, including their choice of two AIMS publications. These workshops can be offered ***in any part of the nation*** based on a minimum enrollment of 30 participants. The cost is $70 per person.

Information Request

Please send current information on:

______ AIMS National Leadership Program
______ AIMS On-Campus Workshops
______ AIMS Off-Campus Workshop Schedule
______ Science Festival
______ Festival of Mathematics
______ "A Day with AIMS" Schedule
______ "A Day with AIMS" hosting information

Name: ______________________________

Address: ______________________________
Street City State Zip Code

Mail to: **AIMS Education Foundation, P.O. Box 8120, Fresno, CA 93747**

INTRODUCTION

Bubbles have long been a favorite preoccupation of children and adults; bubble solutions and blowing tools continue to be popular items on store shelves. Why not use this motivating force to observe and discover what soap films and bubbles can help us learn?

Where will this soap film journey take us? The answer may surprise you as it did me. From simple wonder, we can advance into the world of geometry, physics, and chemistry. We can study classic minimal surface problems posed by mathematicians and scientists over a century ago. We can learn about molecules, surface tension, light waves, air pressure and patterns, all by observing soap films. Math and science come together naturally in this environment.

These activities combine the learning of content along with the use of scientific processes. Without knowledge, we would not know what questions to ask or hypotheses to form. That's why the fact sheets and background information are so important. A selective bibliography is included for those who want to read the primary sources.

I invite you on an educational adventure. Wonder, explore, and say "aaah!" along with your students as you dip your hands in a little soap and water and discover the fascinating world of soap films.

ADVICE

Allow time for some free play and exploration before getting into the serious part of the lesson. Soap films hold a natural attraction for kids of all ages.

Recognize that there will always be a battle between soap film experimenting and finding a dry place to record information.

Have old towels or rags handy for cleanup. A vinegar and water solution will cut the soap film residue left on desks or tables. Vinegar may also be sprinkled directly on the surface to be cleaned.

SUPPLY LIST

This list may assist you in assembling the supplies for the activities you have chosen.

Consumable Items

_______ glue
_______ string or thin yarn
_______ straws
_______ liquid soap such as Dawn or Joy
_______ assorted gumdrops
_______ round toothpicks
_______ 18 or 20 gauge solid core copper wire
_______ plastic wrap
_______ masking tape
_______ cotton thread
_______ wax paper
_______ vinegar
_______ baking soda

Non-consumable Items

_______ metric rulers
_______ calculators
_______ scissors
_______ protractors
_______ compasses
_______ wire cutters
_______ soldering iron and solder
_______ water containers — half gallon milk cartons, liter boxes, tubs, styrofoam or plastic cups, plastic aquariums, etc.
_______ kitchen tools, gadgets with unusual holes, cookie press, cake decorating tubes, strawberry baskets
_______ commercial bubble wands and solution
_______ wool sample
_______ pairs of rings — jar lids, crumpet rings, tuna cans, soft margarine tubs, plastic bracelets
_______ glass or plexiglass plates, 4" × 4"
_______ thumbtacks
_______ plasticine clay
_______ glass quart jars
_______ cleanup rags, old towels
_______ cookie sheets or cafeteria trays
_______ eyedroppers
_______ construction paper, scratch paper
_______ straight pins
_______ sets of small chains 3 feet in length
_______ blank transparencies
_______ watch or clock with secondhand
_______ round plates, saucers, pie plates, or paper plates

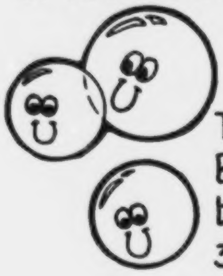
SOAP SOLUTION RECIPES

Many factors contribute to the making of a good soap solution. Consider tap versus distilled water, warm versus cold water, the kind of soap, the additives, and the amount of each ingredient. Cost, also, must be weighed against benefits.

To complicate matters, soaps have various stabilizing additives of their own. Unfortunately, these additives are not listed on the labels so comparison is difficult. Try soaps in different price ranges. Try additives such as sugar, syrup, lemon juice, gelatin, and glycerin. Glycerin is available in drugstores.

Several investigations in this book are devoted to finding the optimum solution. However most bubble experiences do not require a special recipe. Just squirt some liquid dish soap into water, stir and blow.

This collection of ordinary, unusual, and historic recipes has been gleaned from books, magazines, and science museums. Although sophisticated solutions can be created in chemical laboratories, most of the following solutions can be made in your home or school.



BASIC RECIPES

The Exploratorium in San Francisco, site of several Bubble Festivals, recommends this recipe. For best results, let it age at least five days.

3.8 liters	1 gallon	water
175 ml	2/3 cup	Dawn or Joy detergent
15 ml	1 tablespoon	glycerin, optional

(960ml) 1 quart water
(120 ml) 1/2 cup soap
Glycerin, optional

50% distilled water
40% good liquid detergent
10% glycerin

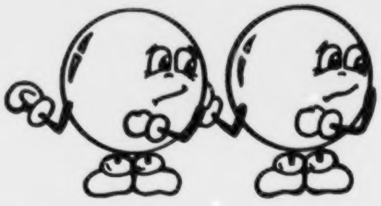
Tap water
1-2% soap

2 parts water
3 parts soap
1 part glycerin

3 parts water
1 part soap
3 parts glycerin

5 parts water
1 part soap
1 glycerin

SOMETHING DIFFERENT



60 ml cold water
15 ml unflavored gelatin

Heat to 90 Celsius (almost boiling) in double boiler. After it is dissolved and there are no bubbles, add

9 ml glycerin
3 ml liquid detergent

Stir gently; keep warm while using. Bubbles can be mounted on heavy paper or rolled across smooth surfaces.

Historic Solution

These solutions are more difficult to make but are included for their historic value.

JOSEPH PLATEAU'S SOLUTION (1873)

Sodium oleate is an white powder available from dealers in chemical supplies.

40 oz. distilled water
1 oz. pure sodium oleate

Do not stir but set in a dark place for 24 hours to dissolve.

10 oz. U.S.P. glycerin

Mix by pouring back and forth between two clean containers. Store in a dark place about one week. Siphon off the clear fluid below the scum. To the clear fluid add

2 drops household ammonia

Bottle for use.

CHARLES V. BOYS' SOLUTION (1890)

A variation of Plateau's

Fill a clean stoppered bottle 3/4 full of water. Add 1/40th the water's weight of sodium oleate. It will probably float. Leave in the dark for a day to dissolve. Add pure glycerin to nearly fill the bottle and shake well. Leave the closed bottle in a dark place for about a week. Siphon the clear liquid from the scum. Add one to two drops strong liquid ammonia to every pint of liquid.

To use, put the amount needed into another container. Leave the original stored. Do not return the leftover solution to it. Do not warm or filter. Do not expose to air unnecessarily. (Boys' solution lasted ten years.)

BUBBLE PERSONALITIES

JOSEPH ANTOINE FERDINAND PLATEAU
(1801-1883)

This Frenchman spent much of his life studying the surface properties of fluids, despite being completely blind by the age of 42. (His eyes were permanently damaged from looking at the sun during an optics experiment.) The problem of finding the minimum surfaces of three-dimensional figures is now called Plateau's Problem. It is easily done with soap films but was not solved mathematically until 1976. His classic work is entitled Statique experimentale et theorique des liquides soumis aux seules forces moleculaires (Experimental and Theoretical Investigations of the Equilibrium Properties of Liquids Resulting from their Molecular Forces), published in 1873. Much of his research was done at the University of Gent in Belgium.

CHARLES VERNON BOYS (1855-1944)

Boys was well known for giving lecture-demonstrations throughout England, making the study of bubbles and their properties interesting to children and adults. His book, Soap Bubbles, Their Colors and Forces Which Mold Them, is the classic work on bubbles in the English language.

EIFFLE PLASTERER

Since age 25, this former high school physics teacher and sorghum farmer from Huntington, Indiana has been experimenting with bubbles. He created "Bubbles Concerto", a show combining science and entertainment, and has presented it over 1,400 times since 1932.

Plasterer makes his solutions in concentrated form and then adds two parts water to one part concentrate. One of his concentrates is made from sassafras roots. Of the many soap solutions he has tried, one gave him a bubble that lasted 340 days! This particular bubble was breath-blown to four inches in diameter and kept in a closed jar. It never popped, but slowly lost air until it disappeared. He uses another solution for making giant bubbles that can enclose seven people.

Approaching the age of 90, he still blows bubbles. In April of 1986, he appeared at the Second International Bubble Festival hosted by the Exploratorium in San Francisco.

TOM NODDY

Whether putting on a show in a school, in a prison, at a museum, or on television's "Tonight Show", Tom Noddy from Santa Cruz, California has fascinated people with bubble magic. He blows chains of caterpillar bubbles, square bubbles, bubble families, bubbles inside bubbles, bubble volcanoes, and spinning bubbles to name a few. He became interested in bubbles while saving money for a trip to Europe. Noddy continues to learn from scientists and bubble lovers all over the world.

WHET YOUR APPETITE

I. Topic Area

Large bubbles

II. Introductory Statement

Through the excitement of creating large bubbles, students will brainstorm what they would like to explore about bubbles.

III. Math Skills / Science Processes

Math Skills	Science Processes
a. Measuring length	a. Observing

IV. Materials

1-2 straws per person
string
soap solution
4 or more tubs to hold solution
student activity sheets, 1 per group

V. Key Question

What would you like to find out about soap bubbles?

VI. Background Information

This open-ended activity can be used as an introduction to the study of soap bubbles or for entertainment. Its intent is to foster creative thought and stir up questions based on observations.

VII. Management Suggestions

1. Do this activity outdoors. Have tubs and solution ready.
2. It is easier to achieve free-floating bubbles with the small frame. After success with the small frame, try the large frame.
3. Frame construction will take about 10 minutes. Exploration time can go on indefinitely.
4. The key to this lesson is the brainstorming and discussion that follow the fun exploration, so allow a suitable amount of time for it.

VIII. Procedure

1. Follow the directions on the activity sheet.
2. During exploration outdoors, try twisting the frame. Can you make two bubbles? Find a partner and interweave your frames as shown on the activity sheet to make a plus sign with the soap film.
3. Back in the room, cooperative groups will record questions and things observed.
4. Share ideas with the whole class.

IX. Discussion Questions

1. What did you observe about your bubbles? (popped after a short time, colors in soap film, soap film swirled around, etc.)
2. Did you find any special things that you could make the bubbles or soap films do?
3. What would you like to find out about soap films and bubbles?

X. Extended Activities

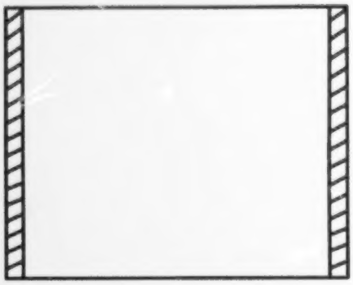
1. Increase the string length to make even larger frames.
2. Partially fill a round wading pool with water and soap. Use a hula hoop to make large cylinders and bubbles. Try enclosing a person in the large bubble. A humid environment is desirable.
3. Blow large bubbles from various sizes of tin cans, cut out at both ends. Try taping several together to make a long blowing tube.
4. Practice with a large bubble maker such as the "Bubble Thing", available in many toy stores. It was created by David Stein, a New York architect.
5. Work on a soap solution recipe which best makes large bubbles.

XI. Curriculum Coordinates

Language Arts:
Launch a study of homonyms with a dictionary study of whet/wet, taken from the title of this activity.

Whet--Your Appetite

Group Names



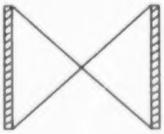
BUILDING THE FRAME

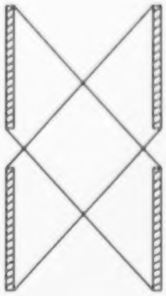
Small	Large
1 straw, cut in half	2 straws
50 cm. string	100 cm. string

Thread the string through the straws. Tie the string together and trim the ends.

EXPLORING

After dipping in the soap solution, hold the frame in front of you and pull it upward. Bring the straws together to make a floating bubble. Experiment and share your ideas with others.





BRAINSTORMING

What would you like to find out about soap bubbles ?

B. Hawsepian

IT'S A TOUCHY SUBJECT

I. Topic Area
Effect of surfaces on bubbles

II. Introductory Statement
Students will discover that bubbles like wet surfaces and also that some dry surfaces will not pop a bubble.

III. Math Skills	**Science Processes**
a. Venn diagram or Set Theory	a. Observing
	b. Collecting & recording data
	c. Classifying
	d. Generalizing

IV. Materials
bubble tools
soap solution in container
wool sample
rug samples, optional
rags for cleanup

V. Key Question
Which surfaces are friendly to bubbles?

VI. Background Information

Bubbles do not pop when they land on wool or some tightly woven rugs. If you were wearing a wool jacket, bubbles could be bounced from one arm to the other. Wool gloves allow you to hold a bubble.

Bubbles love wet surfaces. A wet straw or finger can poke right through a bubble without popping it because the water molecules on the object join together with the water molecules in the soap film. This attraction of like molecules is called *cohesion*. Try poking a straw through a hemisphere or bubble wall and blowing another bubble inside.

The generalization about wet surfaces has an important application to many of the investigations in this book: whenever bubble formations are to be observed, first wet all the surfaces they will touch.

VII. Management Suggestions
1. Decide which of the two forms, structured or unstructured, you wish to use.
2. For the structured form, partners are suggested. One will blow bubbles and the other record the results. This activity may take 40 minutes.
3. If the unstructured format is used, students will design their own experiment to answer the key question. One period will be needed for planning and a second period for performing the experiment they devise.

VIII. Procedure (structured activity)
1. After introducing the key question, discuss some surfaces to test, both inside and outside the classroom.
2. Partners will test and record the surfaces on the Venn diagram. The intersection is for those surfaces which yield inconsistent results.
3. Explore the second question, "How can you poke a bubble without popping it?" without giving hints.
4. Discuss the results with the class and have them generalize their findings.

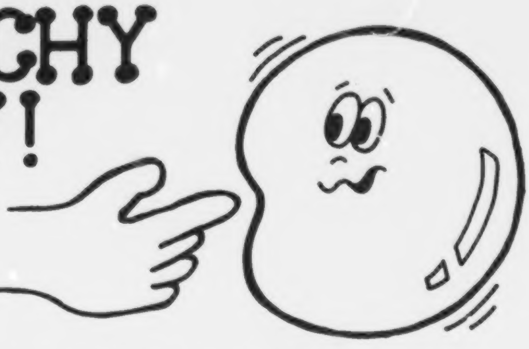
IX. Discussion Questions
1. Which surfaces were unfriendly to bubbles?
2. Do all of you agree? What could have caused different results between groups? (a surface that became wet with repeated trials, wind conditions, etc.)
3. What did you learn about friendly surfaces? (Bubbles like wet surfaces. . . and certain dry ones.)
4. On which surfaces did bubbles sit or float? On which surfaces did bubbles "melt" into the surface?
5. Would someone like to demonstrate how to poke a bubble without popping it? Why did you decide to try this way?

XI. Curriculum Coordinates

Language Arts:
Write a story about the perils of a bubble family as they tried to stay wet and avoid unfriendly surfaces.

Art:
Do a bubble collage by making separate thin mixtures of red, blue, and yellow poster paint with soap added. Blow bubbles with a straw and then bring a white sheet of paper down over them. The "pop" will leave a mark on the paper. Continue to complete the collage using the three colors. Bubble hemispheres blown on a wet surface are easier to work with than floating bubbles.

IT'S A TOUCHY SUBJECT!



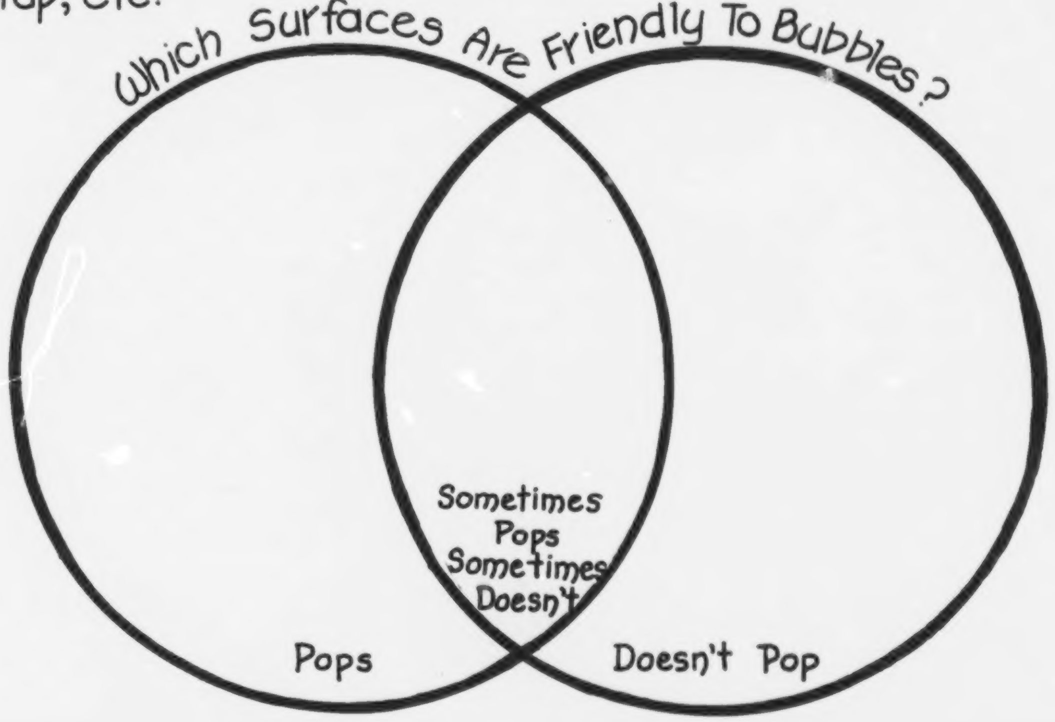
Names ____________________

____

Let bubbles fall on different surfaces. Do the bubbles pop quickly or do they sit on the surface for awhile?

Record on a Venn diagram.

Suggested surfaces: desk, tiled floor, sidewalk, grass, snow, fence, metal, cabinet, wooden door, clothes, rugs, blacktop, glass, wax paper, plastic wrap, etc.

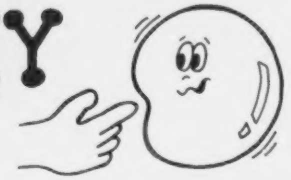

Which Surfaces Are Friendly To Bubbles?
Sometimes Pops Sometimes Doesn't
Pops
Doesn't Pop

How can you poke a bubble without popping it?

____

____

IT'S A TOUCHY SUBJECT!



Design your own investigation to answer this question:
Which surfaces are friendly to bubbles?

What surfaces will be tested?

What will the standard be for determining a friendly versus an unfriendly surface?

How will the results be shown?

What materials will be needed?

TAKING SHAPE

I. Topic Area
Shape of bubbles

II. Introductory Statement
Students will learn that a free-floating bubble will always form a sphere regardless of the shape of the hole from which it was blown.

III. Math Skills	**Science Processes**
a. Working with geometric shapes	a. Observing b. Comparing c. Collecting and recording data d. Generalizing

IV. Materials
bubble tools with differently-shaped holes:
potato mashers, spatulas, toys, rubber bands, tied string, cans, cardboard tubes, plastic lids, paper clips, strawberry baskets, protractors, straws, screens, cake decorating tubes, cookie press forms and cookie cutters, etc.
soap solution and containers

V. Key Question
How many different bubble shapes can you make?

VI. Background Information
Soap film uses the minimum surface area possible within a given boundary. A sphere has the smallest surface area to enclose a given volume of air, therefore all free-floating bubbles are spherical in shape. See the fact sheet, "Keep It To A Minimum".

VII. Management Suggestions

1. Realize that older students will have had prior experience with bubbles and may already think they know the results. Have fun raising some level of doubt in their minds.
2. The day before, ask each student to bring some object for blowing bubbles. Give some examples to encourage a variety of hole shapes. Have some spares for those who don't bring one.
3. Groups of four to six, each with a different tool will work together.
4. Allow 45 minutes or more.

VIII. Procedure
The students will:

1. Record the name of each group member's bubble tool in the first column, and draw the shape of the hole in the second column.
2. Take turns dipping their tool in the soap solution and making bubbles.
3. Record the shape of each person's bubble by naming or drawing it.
4. Complete the student activity sheet. The last question is starred because the teacher will need to discuss the nature of soap film based on Background Information.

IX. Discussion Questions
Why do larger bubbles start out long and wobbly? (They were formed from the rapid movement of your arms and have not had a chance to stabilize yet.)

X. Extended Activities
Find other objects which have a spherical shape — all kinds of balls, the globe, some candies, oranges, some cereals, etc. Do they get their shapes the same way bubbles do?

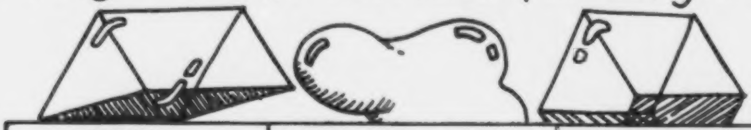
XI. Curriculum Coordinates

P.E.:
On a tumbling mat, scrunch your body into a spherical shape as much as possible and roll in all directions.

Name ______________

TAKING SHAPE

How many different bubble shapes can you make ?



TOOL	SHAPE OF HOLE	SHAPE OF BUBBLE

B. Howsepian

List the shapes you made. ______________________________

Did the bubble shape match the hole from which it was blown ? ______________________________

*Why did you get these results ?

____

____

____

BUBBLE CLUSTERS

I. Topic Area
Bubble patterns

II. Introductory Statement
Students will explore various combinations of bubbles and the structures and patterns which they form.

III. Math Skills
- a. Divergent patterning
- b. Measuring angles
- c. Working with geometric shapes

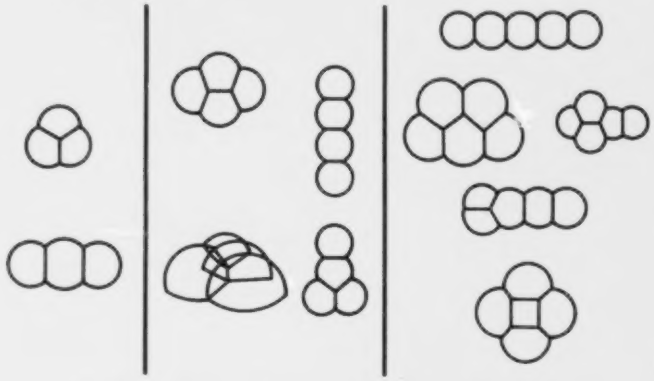
Science Processes
- a. Observing
- b. Collecting & recording data
- c. Applying

IV. Materials
1 straw per person
soap solution
8 or more cookie sheets or cafeteria trays
plastic wrap
masking tape
protractors

V. Key Question
What kinds of patterns do groups of bubbles form?

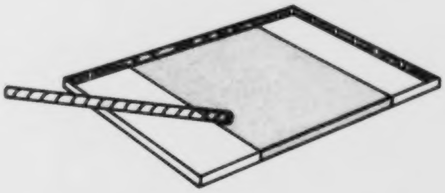
VI. Background Information

This activity taps the creative side of soap bubble exploration. The pattern must be stable or hold its position and the bubbles should be fairly uniform. Include two-layer arrangements. Try different sizes as an extension. Some of the patterns that might be found are:

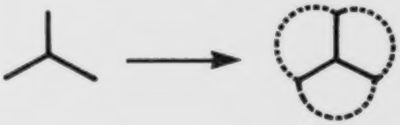


Bubbles trapped between layers, the focus of the second activity sheet, allow for a clearer study of angles and shapes. All surfaces must be wet or the soap film will pop. See the fact sheet, "Nature's Patterns".

VII. Management Suggestions
1. Student groups of 2–4 are suggested.
2. This activity can be divided into two periods. Each one will take 45 minutes or more. Some initial play time is recommended.
3. Bubble clusters can be blown directly on flat tables or in some kind of tray. Wet the surface with soap solution, dip a straw in it, hold the straw at an angle to the surface, and blow. Encourage students to blow uniform bubbles.
4. To set up for the second activity sheet, pour a thin layer of soap solution in a cookie sheet or cafeteria tray. Lay a piece of plastic wrap in the soap solution. Then stretch it tightly over the tray, wet side down, and tape in place. Leave some space at one end or both so straws can be inserted.



5. Advise students that it is easier to draw the patterns if they draw the center lines, or internal angles, first and then add the bubble curves.



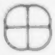
VIII. Procedure

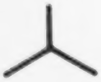
What the Teacher will do:
1. Introduce the key question.
2. Show students how to blow hemispheres.

What the Students will do:

3. Experiment with 3-bubble cluster patterns and record the results. Continue with 4-bubble clusters, etc. The last row is free choice.
4. Share their patterns with the class.
5. Follow the directions on the second activity sheet.
6. Discuss the questions and the observations they made.

IX. Discussion Questions
1. What kinds of patterns do groups of bubbles form? (According to class findings, summarize the number of different patterns for a specific number of bubbles. For example, a 3-bubble cluster has two possible patterns. A 4-bubble cluster has four possible patterns.)

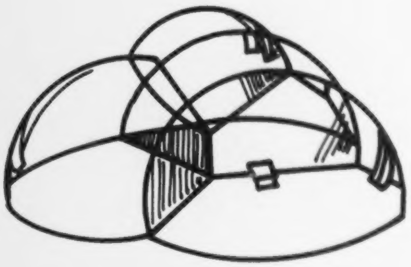
2. Did you build upon previous patterns when you explored a new cluster? (Hopefully.)
3. Was anyone able to make  ? (No.) Why not? (Soap film only meets at 120 degree angles.)
4. Why doesn't the soap film form a sphere or hemisphere in the second activity? (The film is trapped between two layers so it can't assume its free-floating shape.) What shape does it form? (cylinder)
5. Are the angles the same or different? (same) What do they measure? (120 degrees)
6. What basic line structure do you observe most often?



X. Extended Activities

1. Find the volume of a cylinder blown between two layers. The formula for the volume of a cylinder is $V = r^2 \pi h$. (radius squared x 3.14 x height)
2. If you blew a hemisphere and then squashed it between two layers, how different would the radius or diameter be between the two forms? Remember the volume of air is the same. What variable would change your answer? (the height between the layers)
3. The following idea, in a different form, is also covered in the activity, "Reflections on Geo-Panes":

   Make a cluster of three bubbles. Then blow a fourth one above their intersection, forming a second layer. It takes some practice to blow it just enough so that it does not touch the bottom surface. If it does, it will change form and not be useful. Observe the cluster.



   a. How many surfaces meet to form a line? (3)
   b. At what angle do you think they meet? (120°)
   c. How many lines come together at a point? (4)
   d. Guess the angle at which they join. (Students should realize it is more than a right angle and less than 120 degrees. The actual angle is slightly more than 109 degrees.)

   These observations are the core of the classic soap film studies made by Joseph Plateau, a 19th century scientist.

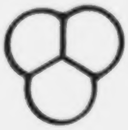
BUBBLE CLUSTERS

____

____

Names

What kinds of patterns do groups of bubbles form ?

3					
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WATER RINGS

I. Topic Area

Surface tension

II. Introductory Statement

Students will compare the surface tension of water with that of soapy water.

III. Math Skills

a. Measuring length

Science Processes

a. Making & testing hypotheses
b. Observing
c. Comparing
d. Collecting & recording data
e. Generalizing

IV. Materials

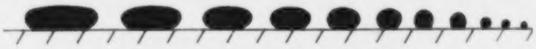
water
liquid soap
Per group:
  1 eyedropper or straw
  4" x 12" (approximate) piece of wax paper
  1 or more toothpicks
  metric rulers
  30 centimeters or more of *cotton* thread
  water container such as a foam or plastic cup, petri dish, or small milk carton

V. Key Question

How does the surface tension of water compare with the surface tension of soapy water?

VI. Background Information

A small drop of water on wax paper forms a very rounded shape. As the volume of water increases the drop of water flattens and spreads out. There are two main forces at work, surface tension and gravity. With small quantities of water (drops) surface tension is the dominant force and it pulls the water into a rounded shape. As the quantities of water increase and the drops get larger, gravity takes over as the major force acting on the water and it pulls the larger drops into a flatter shape.



FAMILY OF WATER DROPS

When soap is added to a drop of water it immediately spreads out over the surface of the wax paper. This happens because soap weakens the cohesion (attraction of like molecules for each other) which causes the surface tension in the water. Gravity then takes over and pulls the water into a thin layer on the wax paper.

Soap makes water "wetter" by reducing its surface tension and allowing it to soak into materials that it normally couldn't penetrate because of that surface tension. When clothes are washed, soap allows the water to penetrate between fibers. When the surface tension and cohesion of the water are reduced, the adhesion (attraction of unlike molecules for each other) between the water molecules and the fibers of the clothes allow the soapy water to soak in and clean.

The surface tension of water is much greater than that of soapy water. Soap reduces the surface tension of water by two-thirds.

When soap is added to the inside of the loop in the second activity, it becomes circular. The soap reduces the surface tension inside the loop and the greater surface tension outside the loop pulls it into a circular shape. Conversely, when soap is added outside the loop, the greater surface tension inside the loop pulls it together.

See the fact sheet "It's a Small World" for more information on surface tension.

VII. Management Suggestions

1. Mix about a cup of soap solution for the whole class; each group will need less than a spoonful. Have students dip their toothpicks in the cup when needed or distribute the solution in small containers.
2. Be sure to do this activity on a flat surface.
3. Groups of 2–4 are suggested.
4. Allowing for some exploration, this activity will take about 60 minutes.

VIII. Procedure

1. Divide class into groups and pass out the materials and the first activity sheet.
2. Predict which liquid has greater surface tension and record predictions on the activity sheet.
3. Follow the directions on the activity sheet.
   a. Optional: draw diameters before measuring.
   b. Have students place the wax paper over the circles but above the lines where they will be drawing the side view. Encourage them to fill the circles as best they can; the water drops will not always stay exactly within the boundary lines.
4. Pass out the second activity sheet and the materials needed and continue with the second activity. If a thread loop sinks, have the group make a new one. Once it is wet, it will not float.
5. Discuss the results and record your conclusion.

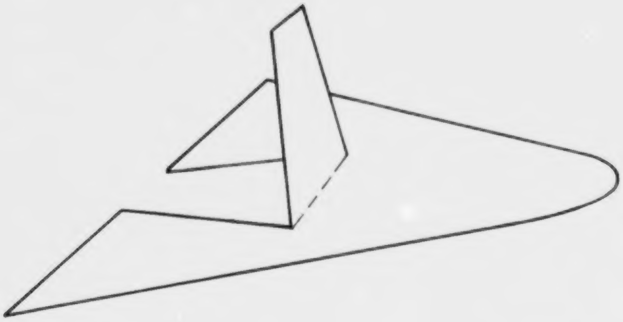
IX. Discussion Questions

1. What is the effect of adding soap to water? (It spreads the water over a larger area. The surface tension is reduced.)

2. How do your drawings of drop C, without and with soap, compare? (Without soap, it touches a smaller area of the paper, has more height, and is more rounded. With soap, it is flatter and covers a larger area of the paper.)
3. Is the strongest pull inside or outside the loop? (Outside, because water alone exerts a stronger pull than water with soap.)
4. What conclusion can we reach? (Water has greater surface tension than water with soap.)

X. Extended Activities

Make a simple boat out of tag. Float it on water in a sufficiently large container. Dip a finger in soap solution and briefly touch the water in the gap at the back end. What happens? (The boat moves forward, drawn by the stronger pull of the plain water as opposed to the weakened pull at the rear of the boat.) Each trial requires a rinsed container and new boat. Try boats of different sizes in separate containers. Which goes faster? Further? Try differently-shaped boats.



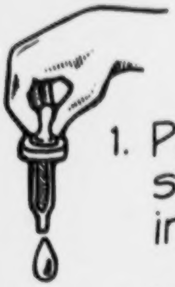
WATER RINGS

Names ______________
____
____
____

How do the surface tensions of water and soapy water compare?

Surface tension is the pull which holds molecules together on a liquid's surface. The tighter this elastic skin is, the greater the surface tension of the liquid.

Predict which has greater surface tension – water or water with soap. ______________________

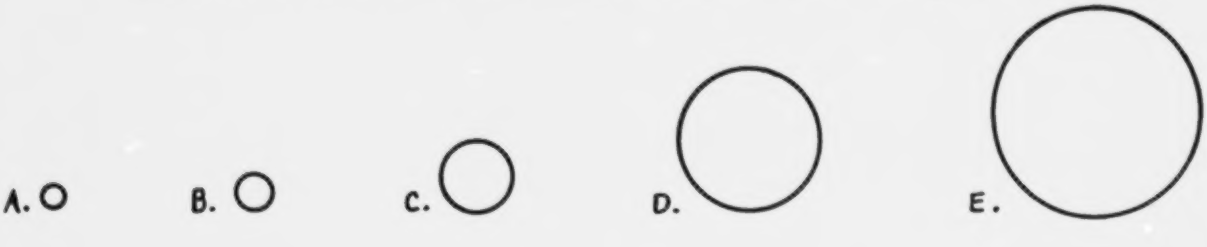


Experiment I

B. Howsepian

1. Place a large drop of water on wax paper. Spread it into smaller drops with a toothpick. Can you bring them into one drop again?

2. Measure and record the diameter of each circle. Cover with wax paper and fill each one with drops of water. Look at them from the side and draw what you observe.



___mm ___mm ___mm ___mm ___mm

diameter

_______ _______ _______ _______ _______

side view

3. Dip the tip of the toothpick in soap solution and touch it to the water ring "C". What is the effect of adding soap to water? ______________________
____

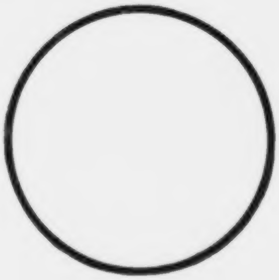
WATER RINGS

____

____________________ Names

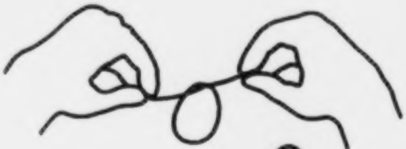
EXPERIMENT II

1) Tie two separate loops of thread, each somewhat bigger than a quarter. Float one loop in water. Dip the tip of a toothpick into soap solution and touch it inside the loop. Draw what you observe.


top view

Is the strongest pull inside or outside the loop? ____________________

2) Dump the water and loop. Thoroughly rinse away the soap. Float the second loop.



Predict what will happen if you add a bit of soap outside the loop.

SOAP
B. Hovsepian

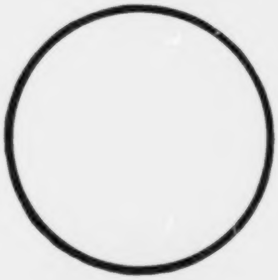
____

____

Why? ____________________________________

____

____


top view

Try it and draw the results.

Conclusion:

These two experiments show that __________________________ has greater surface tension than __________________________.

MACRO MOLECULES

I. Topic Area
Structure of molecules

II. Introductory Statement
Students will build and use models of water and soap molecules to help them understand surface tension and the chemistry of soap film.

III. Math Skills	**Science Processes**
a. Counting	a. Comparing
b. Patterning	b. Applying

IV. Materials
3-D model:
  4 gumdrop colors per group
  (18 of one color, then cut in half
  16 of another color
  4 of another color
  1 of another color)
  about 20 toothpicks
  scissors or knife
  ruler
2-D model:
  glue
  scissors
  construction or scratch paper

V. Key Question
How do soap molecules behave in water?

VI. Background Information

Atoms are joined together in many different combinations to make molecules. These atoms and molecules make up all the matter in our universe. Atoms are incredibly small, 2 hundred-millionths of a centimeter in diameter. In a drop of water, there are 100 billion billion atoms. Since water is made from three atoms, two hydrogen and one oxygen, there are about 33 billion billion molecules in that drop. Students need to realize their models are huge versions of the real thing, yet very important for comprehension.

The soap molecule model used in this lesson is called sodium palmitate. Sodium soaps are solid at room temperature while potassium soaps are liquid.

There is special value in the "people" molecule idea. Whenever a concept can be related to our own physical movement, the possibility of understanding is increased. Seymour Papert, one of the developers of the Logo programming language, would call such a concept body syntonic.

Some scientific information is given on the activity sheets. For further explanation, see the fact sheet, "It's a Small World".

VII. Management Suggestions
1. Decide which model the students will construct, 3-D or 2-D.
   a. Use of the 3-D gumdrop model is desirable since it gives a more accurate picture of the actual molecules. Join carbon atoms with toothpicks but the cut hydrogen atoms should stick directly onto the carbon atoms. For construction clarity, the drawing shows space between the carbon atoms. They should slide next to each other with no space. The different kind of bond between the sodium and carbon atoms is best illustrated with small magnets rather than a toothpick.
   b. If making the 2-D paper model, glue atoms directly to each other. Scratch paper underneath will help avoid messes. Molecules may also be glued to construction paper.
2. When acting out the "people" molecules, no more than two hands (hydrogen) should touch any oxygen atom. An alternate idea: Students hold hands in a circle and someone tries to break them apart, showing the stickiness of water. Dip hands in soapy water and join again. Now someone can break them apart, illustrating how soap lessens the surface tension.
3. Allow two periods for this activity, about 45 minutes to construct the models and about 50 minutes to discuss scientific concepts and use the models.
4. Small groups can build molecules together.

VIII. Procedure
What the Teacher will do:
1. Explain how atoms combine to form molecules.
2. Discuss the construction of the molecule models.

What the Students will do:
3. Construct two or more water molecules and one soap molecule.

What the Teacher will do:
4. Discuss the Big Idea found on the third activity sheet.
5. Direct the movement of "people" molecules.

What the Students will do:
6. Use their water molecules to show hydrogen bonding and draw what they did.
7. Use their soap molecules to show their behavior in water and draw the results.

What the Teacher will do:
8. Discuss all or parts of the fact sheet, "It's a Small World", to further clarify concepts as appropriate to the students' level.

IX. Discussion Questions
1. In plain water, how do water molecules act toward each other? (The hydrogen atoms of one water molecule are attracted to the oxygen atoms of another, forming a bond. The strength of the bond is its degree of surface tension.)
2. How are the head and tail of soap molecules different? (The head likes water, the tail doesn't.)
3. How do soap molecules behave in water? (They come between the water molecules in their effort to get to the surface, lessening the hydrogen bonds. This lowers the surface tension. On the surface, their tails stick up in the air and their heads are in the water.)
4. What if there is no more room for soap molecules on the surface? (Their tails clump together in the water. See the fact sheet.)

Name ____________________

MACRO MOLECULES

COLOR KEY

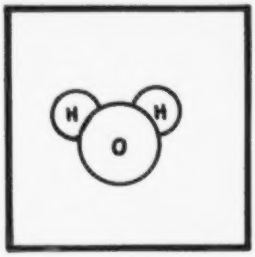
HYDROGEN (H)	
OXYGEN (O)	
CARBON (C)	
SODIUM (Na)	

How do soap molecules behave in water?

Use gumdrops and toothpicks to build models of these molecules. Cut "hydrogen" gumdrops in half.

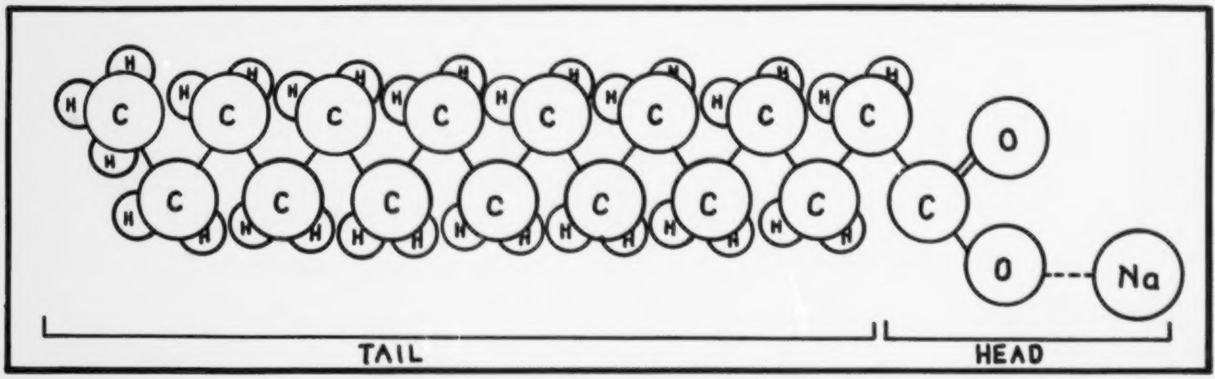
WATER MOLECULES

Each water molecule is composed of two hydrogen atoms and one oxygen atom. It is written H_2O. The hydrogen atoms are joined at 105° angles from the center of the oxygen atom. Build two or more.



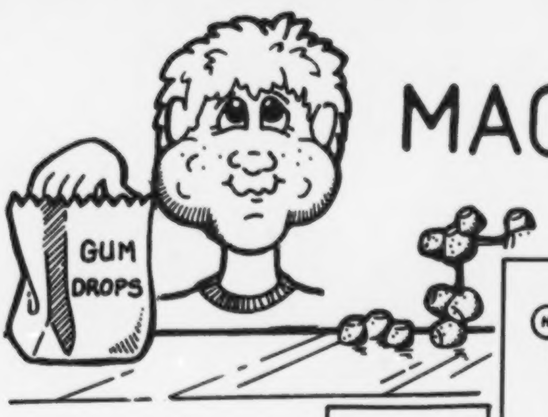
SOAP MOLECULES

All soap molecules have a long, flexible, zig-zag chain made of hydrogen and carbon atoms. Attached to this is a head whose atoms will differ depending on the kind of soap. The model shown here is for hard soap and is written $C_{15}H_{31}CO_2Na$. Can you figure out what it means? Detergent soap molecules have a more complicated head but behave in the same way.

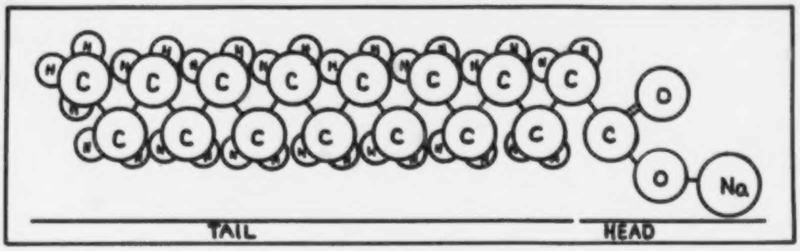


Build one soap molecule. Two hydrogen atoms are attached to each carbon atom except for the tail carbon which has three and the head carbon which has two oxygen atoms.

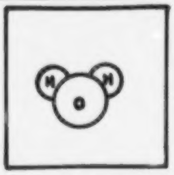
MACRO MOLECULES



Name___________________


H
C
O
Na
TAIL
HEAD

WATER MOLECULE



SOAP MOLECULE

PAPER MOLECULES

Cut out these atoms and glue them together to make two water molecules and one soap molecule.

H H H H H H H H H H H H

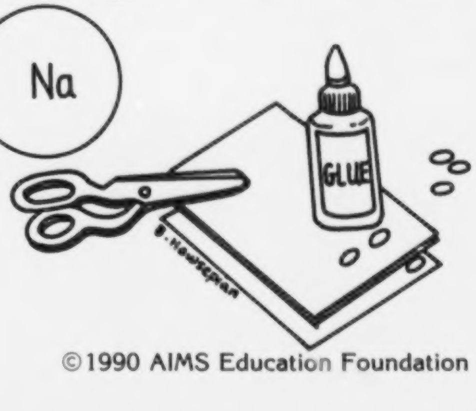
H H H H H H H H H H H H

H H H H H H H H H H H

C C C C C C C C

C C C C C C C C

O O O O Na



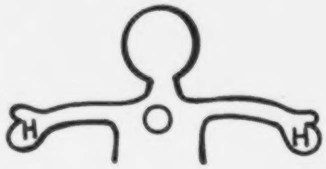
MACRO MOLECULES

Name________________

THE BIG IDEA

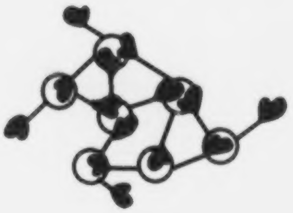
The hydrogen atoms are attracted to the oxygen atoms of other water molecules. This is called hydrogen bonding. The water sticks together, forming strong surface tension. Soap molecules push between the water molecules, weakening that bond. Here are two ways to show the behavior of water and soap molecules.

"PEOPLE" MOLECULES



Place your hands on the shoulders of two different people while they attach themselves to other people. Those hands not attached to another molecule are on the water's surface.

Now chains of three people - the soap - move between the water molecules, carefully breaking the bonds.

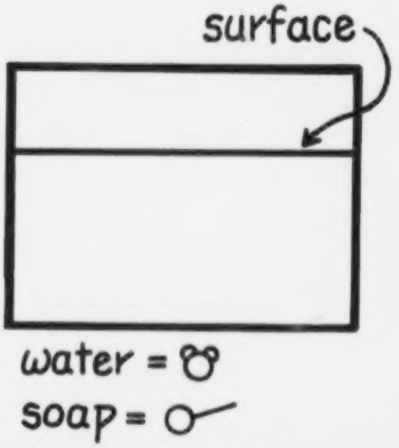


MOLECULE MODELS

B. Hovsepian

Join the water molecules you built with those of another group to show how they are attracted to each other. Use a ruler as the water surface line. Draw what you did.

Soap molecules come between the water molecules, lowering the surface tension. Soap molecules have another characteristic - they stampede to the surface because their tails hate water. The tail sticks up in the air while the head, which likes water stays submerged. Use your model to show the position of soap molecules along the surface. Draw a picture of it.



IT'S A SMALL WORLD

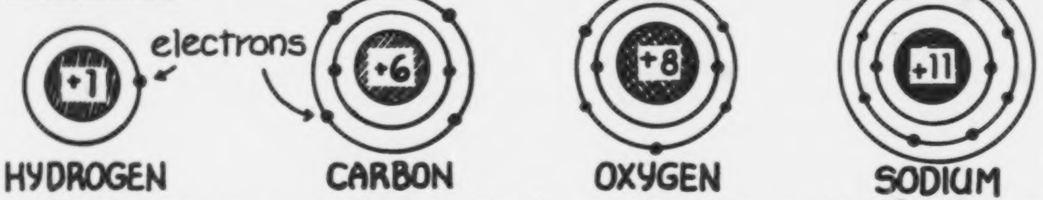
All living and non-living things are made of matter. Matter is anything that takes up space and has mass. This matter can take the form of a solid, liquid, or gas. Matter is made of smaller parts called molecules. Molecules, in turn, are composed of atoms.

There are at 105 different known atoms. Four — oxygen, hydrogen, nitrogen, and carbon — form 96% of all cells or organic compounds. A compound is a substance whose molecules are made of two or more different types of atoms. Carbon is so common that it is part of more than 2,000,000 different compounds. The branch of science which deals with carbon compounds is called organic chemistry. Compared to carbon, the compounds of all other atoms total only about 60,000.

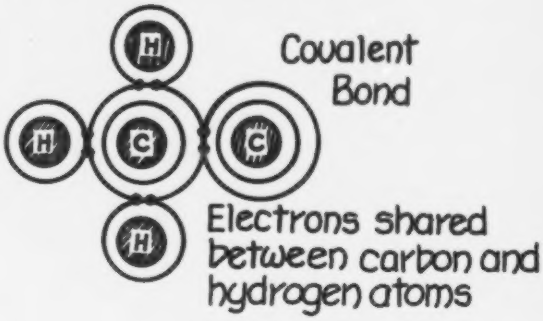
The Structure of Atoms

Atoms have three main components: protons, neutrons and electrons. The protons have a positive charge and determine the atomic number of the atom. The neutron has no charge; it is neutral. Both of these are in the nucleus of the atom. Electrons, which are negatively charged, are found around the nucleus in electron shells. The number of protons, when compared to the number of electrons, determine whether an atom has a neutral, positive or negative charge.

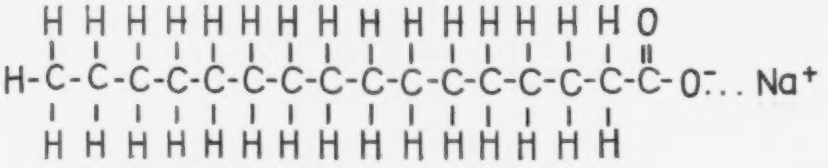
Here are models of the atoms which form water and soap molecules:



The electron shell closest to the nucleus is stable if it has two electrons. The next shell needs eight electrons to be stable, and the next eight again. If they are not stable, they seek other molecules with which to share electrons. Every time two electrons are shared one bond is formed. Oxygen needs two bonds, hydrogen one, and carbon four. Can you see why? When two atoms share electrons it is called a covalent bond. The hydrogen and carbon atoms form covalent bonds in the soap molecule.



This is how the soap molecule is illustrated in a structural formula. Count the bonds. Do the carbon atoms have four? Notice the double bond between the carbon atom at the head of the soap molecule and one of the oxygen atoms. Oxygen atoms need two bonds. How does the other oxygen atom make two bonds?

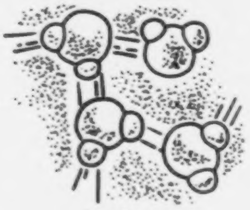


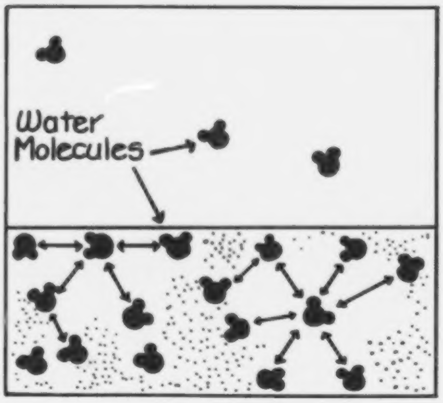
$$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-O^{-}\cdots Na^{+}$$

Sodium Palmitate ($C_{15}H_{31}CO_2Na$)

The bond connecting the oxygen atom and sodium atoms is different. It is called an ionic bond because one atom loses one or more electrons and the other gains them; the electrons are not shared. The attraction is more like that of two magnets than a joining together.

The Chemistry Of Water


Hydrogen bonding



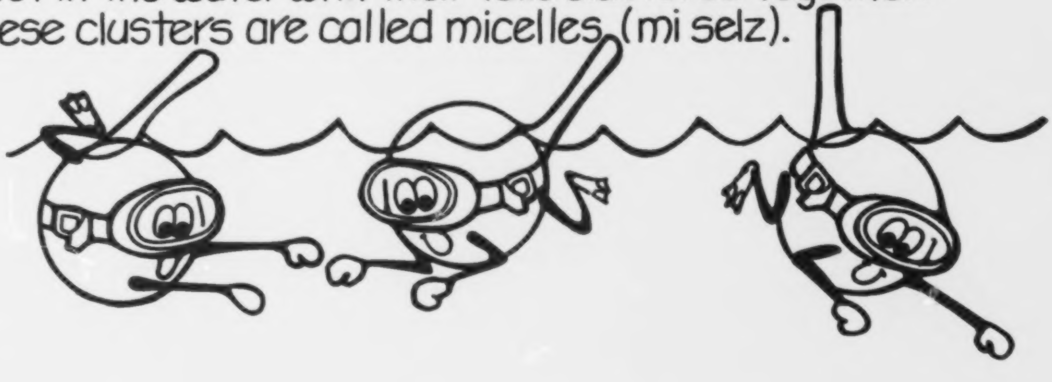
We have discussed two kinds of bonds, covalent and ionic, within molecules. There are also bonds between molecules. Water molecules are made of two hydrogen atoms and one oxygen atom (H_2O). The hydrogen atoms of the water molecule are to the oxygen atoms of other water molecules, forming a strong connection between them. This is called hydrogen bonding. Water molecules stick together like close friends.

The water molecules under the surface are pulled in all directions. For the molecules on the surface life is different. They are exposed to the air. There are a certain number of water molecules present in the air. They are mostly in the form of water vapor (single molecules of water) and their great distance from other water molecules makes the hydrogen bonding extremely weak. As a result, the air does not pull on the water molecules at the surface; all of the pull is coming from the hydrogen atoms in the water. So the surface molecules are pulled only to the sides and downwards, forming a film or skin. This surface tension, or continuous pulling, in water is so strong that bubbles cannot form and last for more than a split second. They are quickly pulled back into the water by the surface tension.

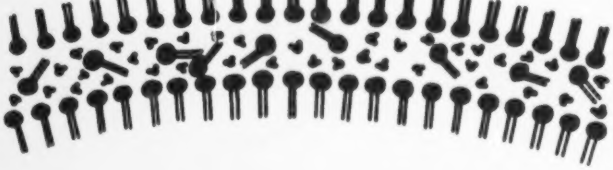
The Chemistry of Soap

To form bubbles, something must be added to water to reduce its surface tension. Soap molecules push the water molecules apart, weakening the hydrogen bonds. This decreases the surface tension, allowing the soap film to be more "stretchy" than plain water. The reduced surface tension of soapy water allows bubbles and soap films to be formed. The soap molecules go to the surfaces of the soap film, delaying evaporation (which ultimately pops the film). Glycerin adds to this protection. The pull of water molecules is three times as strong as the pull of water molecules in soap solution. By adding soap, the surface tension is actually decreased to ⅓ that of plain water.

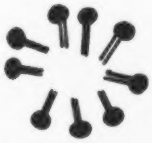
A soap molecule is a thin hydrocarbon chain. The head likes water molecules; it is hydrophilic. The hydrocarbon tail repels water, sticking its waxy tail into the air; it is hydrophobic. Because part of the soap molecule wants so desperately to get out of the water, it makes room by pushing water molecules into the middle of the film. If there is no room at the surface, the extra soap molecules meet in the water with their tails clustered together. These clusters are called micelles (mi selz).



Liquid and hard soap molecules have varying amounts of atoms and their heads may differ, but they behave the same way in water. All soap molecules have a hydrocarbon chain, a tail, generally from 12 to 20 carbons long, which hates water and a head which likes water.



Molecules in soap film



A micelle

Soap film is made of a thin layer of liquid with two surfaces. On each surface are soap and water molecules. Since soap molecules are bigger than those of water, the film can be no thinner than the length of two soap molecules stacked on top of each other, one for each side of the surface. That's about one-millionth of an inch.

Cleaning Powers

The behavior of soap molecules promotes cleaning in two ways. First, surface tension is reduced allowing the soap solution to soak between clothes fibers and dirt particles. The soap actually makes the water wetter. Second, the tails of soap molecules are attracted to grease and dirt.

Remember that soap molecules which can't get to the surface are stuck under water with their tails clustered together. Adding a lot of soap creates so many clusters that the solution gets cloudy. The tails hate water but like oil and grease. When clothes or dishes are washed, the grease and dirt are held in suspension by the tails until being rinsed away.

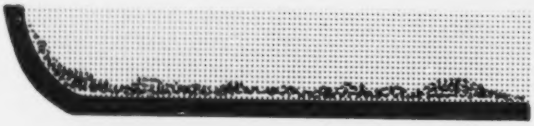
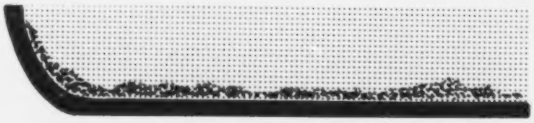
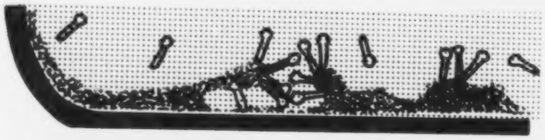


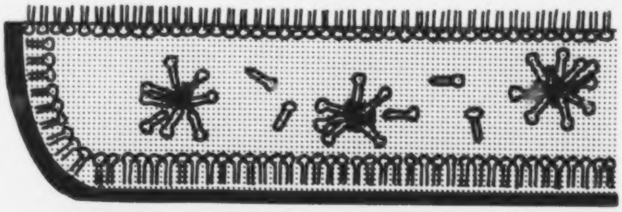
Plate with greasy dirt.



Adding water doesn't affect dirt.



Detergent added. Tails attracted to dirt.



Soap molecule clusters (micelles) holding dirt in suspension.

PULLING STRINGS

I. Topic Area

Soap films — minimum surfaces

II. Introductory Statement

Students will find that soap film pulls equally in all directions and fills the smallest area possible.

III. Math Skills

a. Counting
b. Sequencing
c. Measuring length
d. Finding area
e. Using formulas
f. Using calculators

Science Processes

a. Predicting
b. Measuring & comparing
c. Observing
d. Collecting & recording data
e. Interpreting data

IV. Materials

2 straws cut in half or 4 uncut straws per frame
string or yarn
scissors
white or light-colored thread
metric rulers
soap solution in containers big enough to hold the straw frames
calculators

V. Key Question

What kind of space does soap film like?

VI. Background Information

A key characteristic of soap film is that it always pulls itself into the smallest space possible. That pull is equal in all directions. See the fact sheet, "Keep It To A Minimum" for a fuller explanation.

The geometric shapes, in order from smallest area to largest area, are the triangle (69 squares), the rectangle (88), the square (90), the hexagon (105), and the circle (117). There may be some variation in the square count but the sequence should remain the same. As the shape becomes more nearly round, it increases in area. An octagon would fall between the hexagon and circle.

VII. Management Suggestions

1. Students can work as partners.
2. Some students may find it difficult to tie the thread to the small frame. A larger frame made from four straws might help.
3. Decide which activity sheet for finding area is most appropriate for your students. Students count squares in the easier version and use formulas in the more difficult version.
4. This activity can be done in one extended period or as two separate lessons. The soap film experiment will take about 40 minutes. The second lesson deals with finding areas and discussing results. It will take about 50 minutes.

VIII. Procedure

1. Follow the directions on the student activity sheets.
2. For the second (counting squares) activity sheet discuss what counts as a square. If half or more of a square is inside the figure, count it as a whole square. This will generally balance the smaller parts of squares which are not counted.
3. For the third (formula) activity sheet remind students that letters next to each other in formulas signal multiplication. Also review the meaning of parentheses.

IX. Discussion Questions

First activity (experiment) sheet:

1. Does the hole in the second experiment change its shape when you move it around? (No, the soap film pulls on the thread equally no matter where it is moved.)

Second activity (counting squares) sheet:

2. What does the area table tell you about the hole and the soap film surrounding it? (The hole is as large as possible so the soap film area must be as small as possible.)

Third activity (formula) sheet:

3. What did you discover about the perimeters? (They are the same, 12 centimeters.)
4. List the shapes in order from smallest area to largest area. (triangle, rectangle, square, hexagon, circle)
5. What does the area table tell you about the hole in the second experiment? (It is the largest possible for a given perimeter.)
6. What can you conclude about the area of the soap film that was not popped? (It was as small as possible. Even in the first experiment, the soap film pulled the thread into as much of a curve as the thread allowed.)

General:

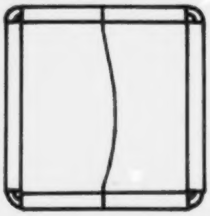
7. If each shape had the same area, which would have the smallest perimeter? (the circle)

Names ______________________

____

Pulling Strings

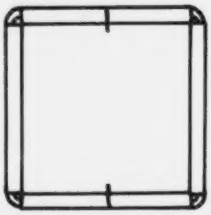
What kind of space does soap film like ?



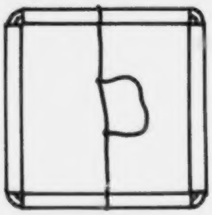
1. Cut two straws in half and tie the four pieces together with string. It will not be rigid. Tie a thread to the middle of opposite straws, leaving some slack.

Predict how the thread will look when the frame is dipped in soap solution and one side is popped. Then draw what actually happens.

PREDICTION



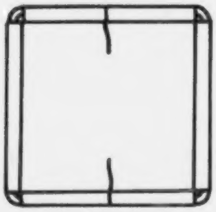
ACTUAL

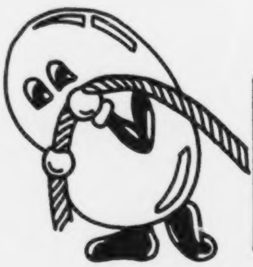


2. Tie an additional thread to the center thread. Tie the loose end further down the center thread and trim.

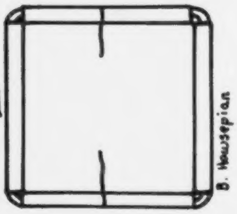
What kind of hole will form when you dip the frame in soap solution and poke the middle ?

PREDICTION



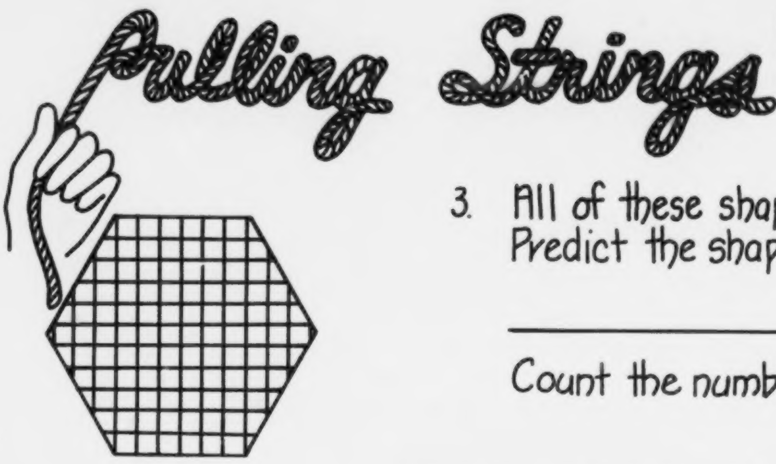


ACTUAL



Try it several times. Then use a pencil or finger to move the hole around inside the frame. Does it change ? ______________________

Pulling Strings



Names ____________________

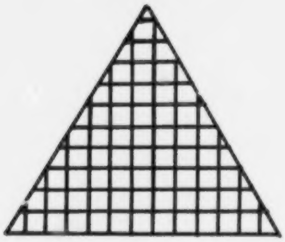
____

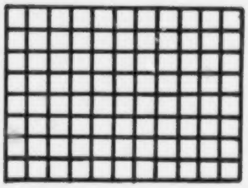
3. All of these shapes have perimeters of 12cm. Predict the shape which has the largest area.

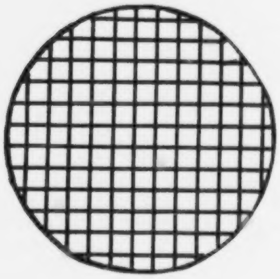
____

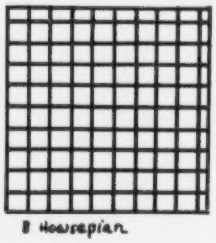
Count the number of squares inside each shape.

HEXAGON	TRIANGLE	RECTANGLE	CIRCLE	SQUARE









List in order, from smallest area to largest.

smallest ____________________

____

____

____

largest ____________________

Refer back to the soap film experiment. What does the area table tell you about the hole and the soap film surrounding it?

____

____

____

____

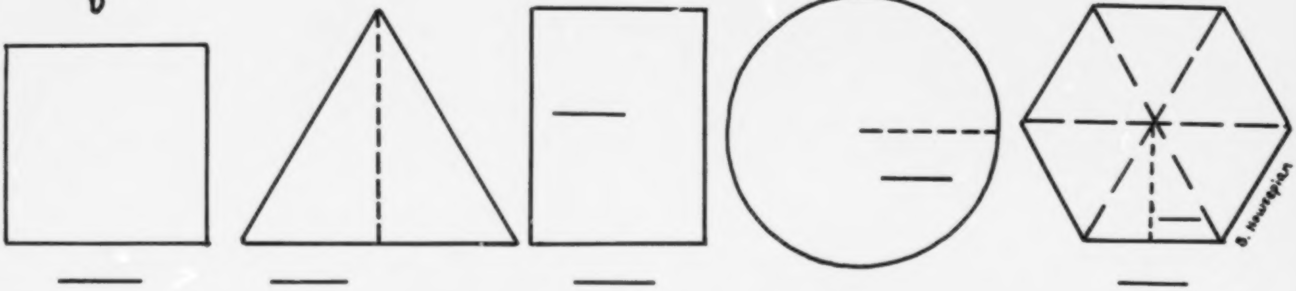
____

____

Names __________ __________

Pulling Strings

3. If the center hole formed the shapes below, what would be the area of each? Measure to the nearest millimeter and complete the table.



SHAPE	PERIMETER	AREA FORMULA	FORMULA WITH MEASUREMENTS	AREA
SQUARE		$A = s^2$	A= __x__	
TRIANGLE		$A = \frac{1}{2} bh$	A= .5x__x__	
RECTANGLE		$A = lw$	A= __x__	
CIRCLE	12 cm	$A = \pi r^2$	A= 3.14x__x__	
HEXAGON		$A = 6(\frac{1}{2} bh)$	A=6(.5x__x__)	

b=base h=height s=side l=length ω=width r=radius $\pi = 3.14$

What did you discover about the perimeters?

____

List the shapes in order from smallest area to largest area.

________ ________ ________ ________ ________

What does the area table tell you about the hole in the second experiment?

____

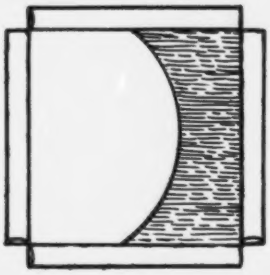
What can you conclude about the area of the soap film that was not popped?

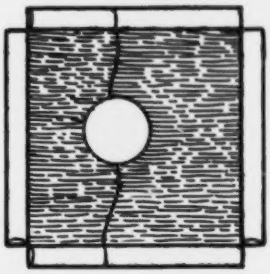
____

KEEP IT TO A MINIMUM

Surface tension is the tendency of liquids to keep their surface area, and the number of surface molecules, to a minimum. All liquids have varying degrees of this property.

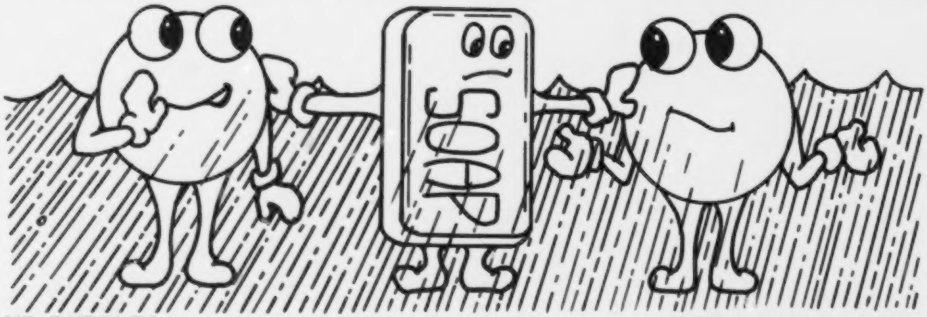
Water pulls together into drops because of cohesion, the attraction of like molecules for each other. In order to form a flat film or bubbles, something must be added to water to prevent the water from pulling into drops. Soap and detergent push the water molecules apart, weakening the hydrogen bonds between them. The surface tension of soapy water is decreased to ⅓ of that for plain water making it more "stretchy". Soap is a surfactant, a substance which acts on the surface of a liquid changing its surface tension.



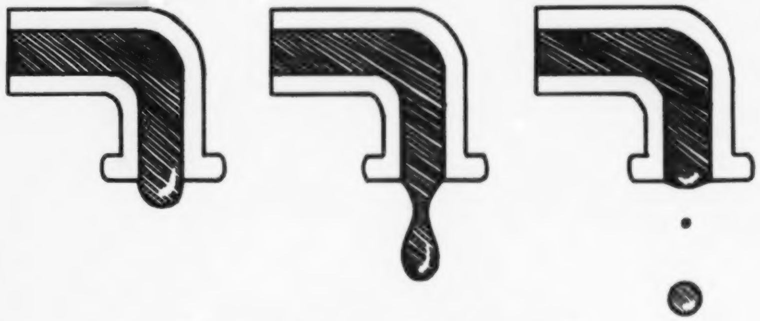


Cohesion between the water molecules in a soap film cause it to pull itself into the smallest area possible. Its energy is conserved. When an area of soap film divided by thread is broken, the largest possible curve for the given length of thread forms. If that curve were allowed to continue, it would form a circle. The open space is as big as possible, meaning the soap film area is as small as possible.

When the loop of thread is popped, the hole is always in the shape of a circle, even if it is moved around. Of all geometric shapes, the circle has the greatest area for a given perimeter.

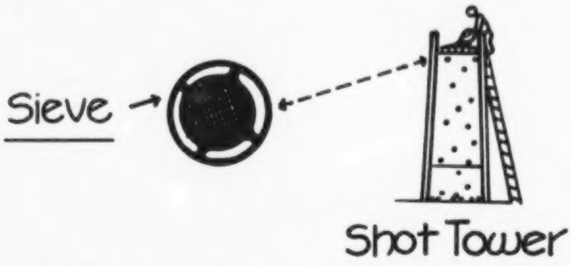


Though the comparison is between water and soapy water, the second experiment in "Water Rings" had a similar result. The stronger surface tension of the water pulled the loop of thread into a circle.



FORMATION OF WATER DROPS

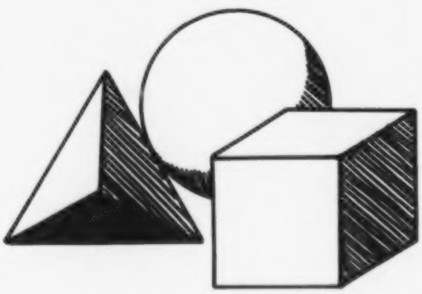
What is the shape of a raindrop? Is it the teardrop shape we have often seen in drawings? Free-falling water such as rain or drops from a faucet are almost perfectly round. Similarly, molten lead poured through a sieve from a shot tower falls through the air into a deep tank of water and arrives as round balls of lead shot.



Stable bubbles also form a sphere no matter what the shape of the hole from which they are blown. A sphere has the smallest surface area for a given volume. Any soap bubble or soap film will take up the minimum surface area possible within a given boundary.

This table shows comparisons of some common three-dimensional figures. All have the same volume, one cubic centimeter. Notice that the more sides an object has, the smaller its surface area. The sphere has the least surface area, proving that soap film finds the minimum shape.

SHAPE	# OF SIDES	SURFACE AREA
Tetrahedron	4	14.7 square cm
Cube	6	6.00 square cm
Octahedron	8	5.72 square cm
Dodecahedron	12	5.32 square cm
Icosahedron	20	5.15 square cm
Sphere	infinite	4.84 square cm



Minimum means the smallest. But soap films sometimes get confused and form several different patterns for the same frame. The hexagon in "A Fork In The Road" is one example. How can there be more than one minimum.? Actually, only one of the patterns is the absolute minimum. The other formations are called relative minimums. They are almost the smallest but not quite. The absolute minimum is more minimum than the others! Why does this happen? It depends partly on the way the object is lifted out of the solution. At what angle is it being held? Which side emerges first?

This minimum surface property has allowed architects, engineers, mathematicians and others to solve some unusual problems using soap films. Some of these problems are included in this book for you to try.

STRETCHING OUT

I. Topic Area

Surface tension and minimum surfaces

II. Introductory Statement

Students will discover a mathematical relationship between the size of two equal rings and the distance soap film will stretch between them.

III. Math Skills

a. Measuring length
b. Using ratios and decimals
c. Finding averages (median, mean)
d. Line graphing
e. Using calculators

Science Processes

a. Predicting
b. Observing
c. Measuring & comparing
d. Collecting & recording data
e. Generalizing

IV. Materials

6-8 pairs of shallow rings

The two rings in each pair should be identical. Each pair should have a circular opening slightly different in size from the other pairs.

Some suggestions:

- cut out the bottom of margarine tubs
- cut margarine tub lids into rings
- cut both ends off of tuna cans
- use pairs of commercial bubble wands
- cut top/bottom sections of styrofoam or plastic cups
- Mason jar lids
- make wire bubble wands in different sizes
- open frisbees
- cut any size hole in dairy carton lids (yogurt, sour cream, cottage cheese)
- pairs of plastic bracelets

metric rulers
soap solution in containers
calculators

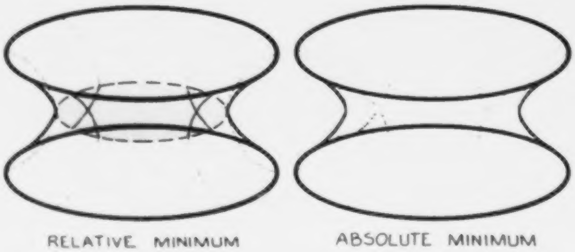
V. Key Question

How far will the soap film between two rings stretch?

VI. Background Information

When two rings are dipped in soapy water and pulled apart, three surfaces often form: a curved one along each side and a flat one in the middle. This is a minimum surface, but it is a relative minimum. The absolute, or greatest, minimum is demonstrated by popping the center film with a dry object. The resulting curves form a catenoid. See the fact sheet on "Catenary Curves".

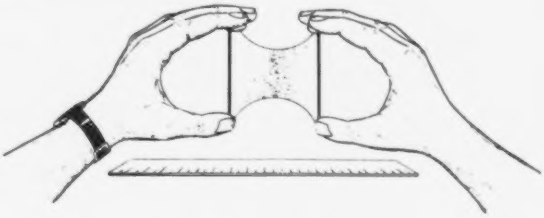
As the rings are stretched apart, the catenary curve becomes sharper until it finally breaks. Mathematically, this has been calculated to happen when the distance between the rings is 1.325487 times the radius of the rings.



It is important to note that the more tests that are run, the greater the chance of getting results close to the mathematical calculation. More samples improve the accuracy of the results.

VII. Management Suggestions

1. Label matching pairs of rings with the same letter so students can compare results.
2. Divide the class into groups of four. If there are plenty of rings available, partners are even better. Start each group with one pair of rings and have them pass them on as data is recorded.
3. Depending on the number of rings used, this activity may take 60 minutes or more.
4. The radius is derived from measuring the diameter of the hole itself, not the outside of the rings.
5. To measure the break, students should lay the ruler on a desk or table and move the rings across it to get a reading. Multiple readings are important.



6. The actual soap film shape drawn should be the absolute minimum, not the relative minimum.

VIII. Procedure

1. Draw the predicted soap film shape between two rings.
2. Measure and test each set of rings. Each group member should be responsible for testing one or more pair of rings. A partner can help pop the center film (if the rings are dipped in solution and held together as they are taken out, the center film can be blown out, then the rings can be separated to form the absolute minimum film).

3. Since multiple checks are needed for each pair of rings, students should record their measurements on the back of the paper, order them from smallest to largest, and record the middle number. This is the median number which is a close approximation of the average.
4. An example of the table might be as follows:

Ring	Radius	Distance At Break	Ratio $\left(\frac{\text{distance}}{\text{radius}}\right)$	Decimal
A	24 mm	33 mm	$\frac{33}{24}$	1.375

5. Plot the data for each pair of rings on the graph, connecting consecutive points with a line.
6. Total the decimal column and divide to find the group average.
7. Compare results between groups and discuss.
8. Find a class average from the group averages and write a generalization.
9. Draw the actual shape of the soap film and write how the shape changes as it is stretched.

IX. Discussion

1. How will we find the radius?
2. For Ring ________, how did your group results compare with other groups in the class? (probably some variation) Why? (differences in the accuracy of measuring, incorrect calculations, etc.)
3. Does the graph form any kind of pattern? (It should, something approximating a straight line.)
4. Is the pattern important? (A straight line means that a rule has been found.)
5. How is the soap film break related to the radius? (The film will break at 1.325 times the radius of the rings.) How close was the class average to this? (The more accurate the measurements, the closer the results should be.)
6. How does the soap film shape change as it is stretched? (The curve becomes sharper until it breaks apart into two separate disks.

X. Extensions

1. Try the experiment with hula hoops. The soap solution will need to be strong for the larger film.
2. Try these variations:
   a. Keep the height constant and move the rings sideways.
   b. Try rings with different diameters.
   c. Try three rings held above each other. More than one person will be needed to hold them.
3. Do the "Arching Links" activity to further explore catenary curves.

S·T·R·E·T·C·H·I·N·G OUT

GROUP NAMES

____

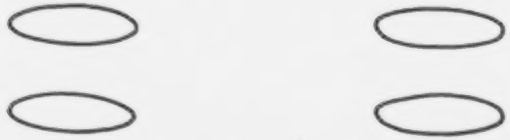
____

____

____

Predict, by drawing, the shape of the soap film when it connects two rings. Then draw the actual shape.

PREDICT ACTUAL



How does the soap film shape change as it is stretched?

____

____

Find the radius of each pair of rings. Dip them in soap solution and pop the center film. Hold close to a ruler and slowly stretch apart, keeping the rings directly across from each other. Measure the distance when the film breaks at least three times before recording.

GROUP RESULTS

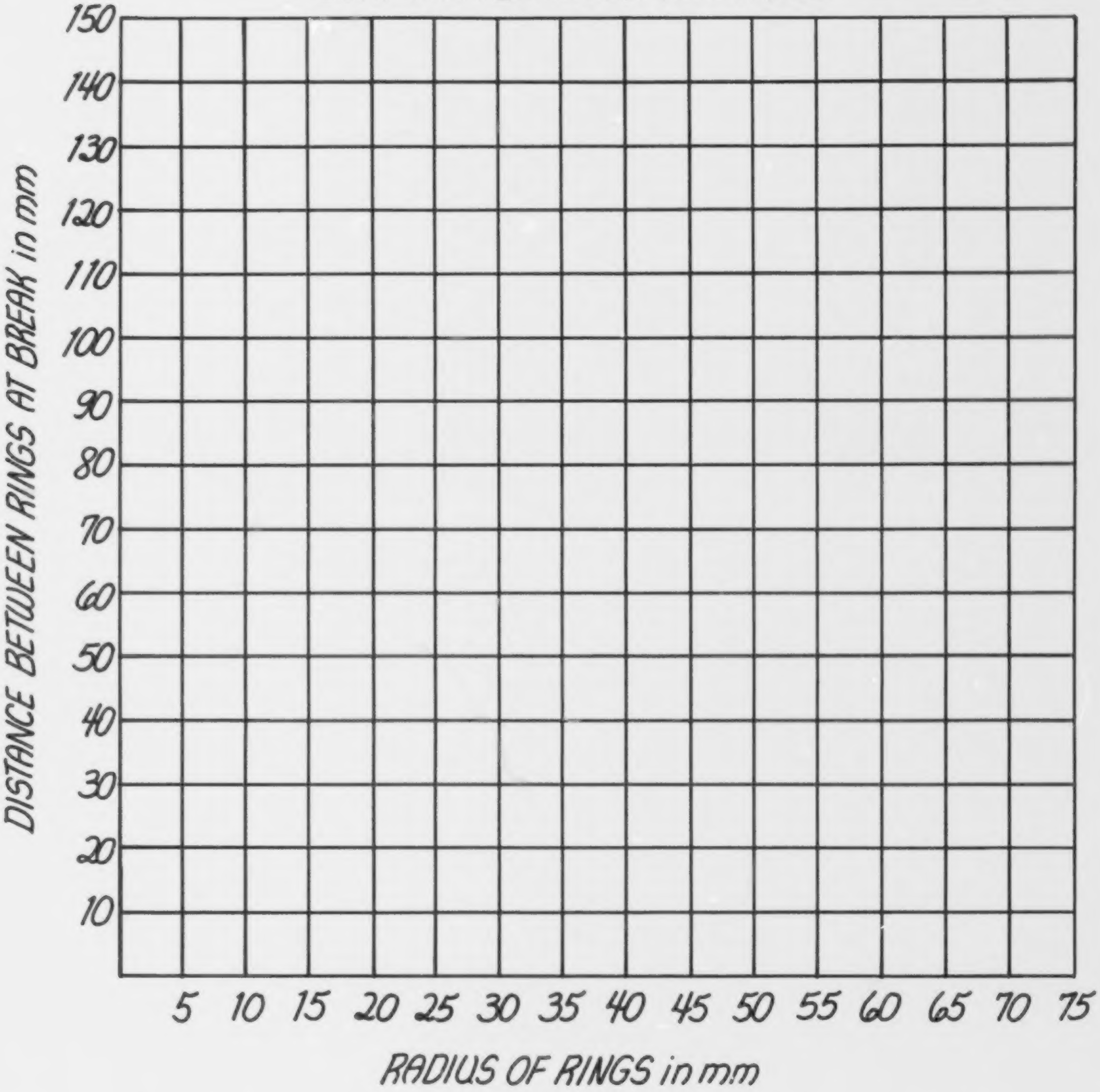
RING	RADIUS	DISTANCE AT BREAK	RATIO $\left(\frac{\text{DISTANCE}}{\text{RADIUS}}\right)$	DECIMAL
A				
B				
C				
D				
E				
F				
G				
H				
			AVERAGE	

B. Housepian

S·T·R·E·T·C·H·I·N·G OUT

Name ____________________

SOAP FILM BETWEEN TWO RINGS



How is the soap film break related to the radius?

____

____

ARCHING LINKS

I. Topic Area
Catenary curves

II. Introductory Statement
Students will observe the patterns of hanging chains and relate them to the soap film curves between two rings.

III. Math Skills	**Science Processes**
a. Patterning	a. Observing
b. Measuring	b. Comparing
	c. Recording data
	d. Controlling variables
	e. Applying

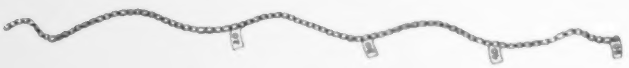
IV. Materials
Two or more sets of small chains (or pieces of limp string). Each set includes one 30 centimeter and one 50 centimeter length (three feet of chain will make a set), available at hardware stores.
wire cutters
masking tape
straight pins

V. Key Question
What kinds of patterns are formed by hanging chains?

VI. Background Information
This activity explores the basis of the soap film curves formed in "Stretching Out" and nurtures students' awareness of patterns. See the fact sheet, "Catenary Curves" for more information.

VII. Management Suggestions

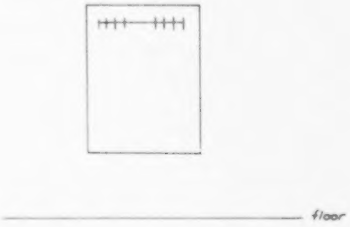
1. With a wire cutter, cut the chains to the lengths needed. With a piece of masking tape, mark and label each 50 centimeter chain at the 20, 30, 40, and 50 centimeter distances.



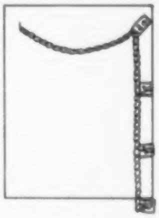
2. If it is difficult to get lengths of chain, certain types of string will work. The string must be very limp so that it hangs freely and forms a catenary curve.
3. This activity is best done with partners. If sets of chains are limited, it can be done by consecutive sets of partners throughout the day or over a period of several days.
4. Chains must hang vertically.
5. Use the fact sheet, "Catenary Curves", after the investigation is completed.

VIII. Procedure
What the Students will do:

1. Attach the first activity sheet to a bulletin board, placing pins at each slash mark. The line must be parallel to the floor.



2. Follow directions on the activity sheet.
3. Attach the second activity sheet to a bulletin board, placing pins at both points marked D.
4. Hang the end of the chain and the 20 centimeter mark on the two pins at point D. Ignore the extra part of chain. Trace the curve.



5. Repeat the procedure, changing one end to the 30 centimeter mark, then 40 centimeter, and then 50 centimeter.
6. Complete the question.
7. Discuss the results.

IX. Discussion Questions

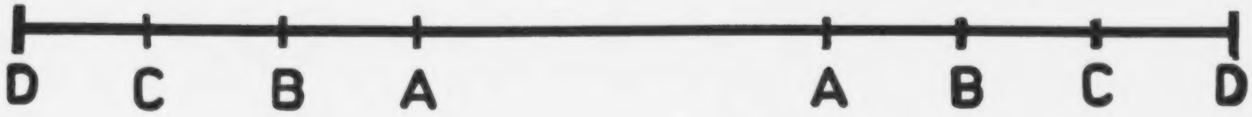
1. First activity sheet: How do the curves change? (The wider apart the ends are set, the less sharp or gentler the curve.)
2. Second activity sheet: How do the curves change? (The longer the chain, the sharper the curve.)
3. Which sheet best illustrates what is happening to the soap film shape in "Stretching Out"? (The second one. Even though the ends on the page are stationary and the rings in "Stretching Out" are being moved apart, the differing lengths of chain show the stretching patterns of the soap film. As the film or chain length is increased, the curve sharpens.)
4. Can you find any examples of catenary curves in the real world? (Gateway Arch in St. Louis. . .)

ARCHING LINKS

____

____

Names



1. Same lengths/different widths

Attach the ends of a 30 cm chain to the points labeled A. Trace the curve. Then match B to B, etc. How do the curves change ?

____

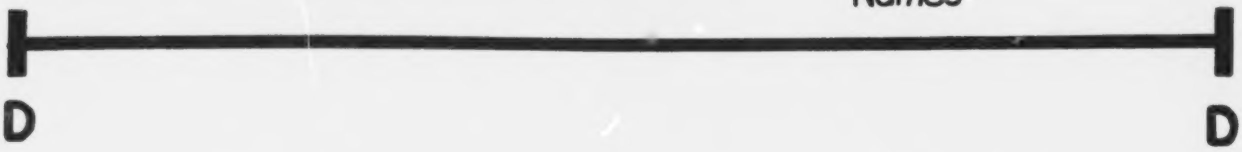
____

ARCHING LINKS

____

____

Names

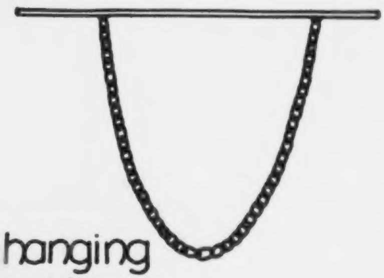


2. Different lengths/same width

Attach the end and the 20cm mark to the points labeled D. Trace the curve. Change to the 30cm mark, then 40 and 50cm. How do the curves change? ______________________

____

CATENARY CURVES AND CATENOIDS



A catenary curve is the curve formed by a hanging chain. The name is taken from the Latin word, *catena*, meaning chain. The weight or thickness of the chain doesn't change the curve, its shape is determined solely by the length of the chain and the spacing of its end points.

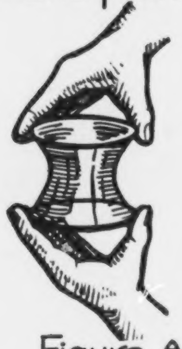


Figure A

A Soap Film Catenoid

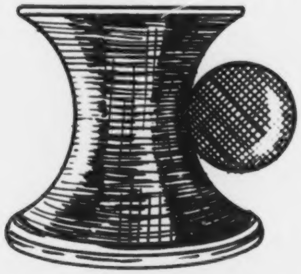


Figure B

Curve Relationships

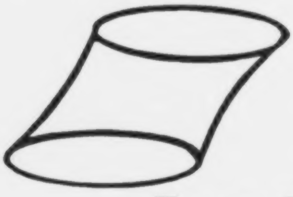
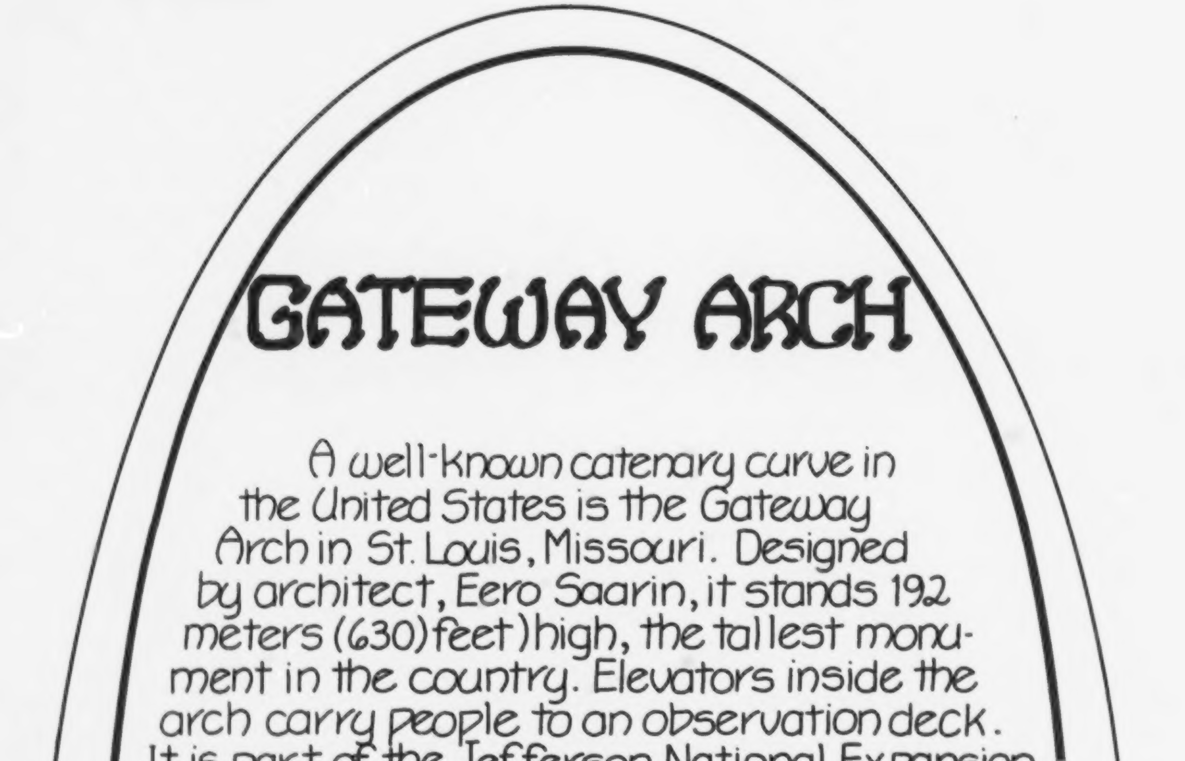


Figure C

Distorted Curve

Soap film forms a catenoid when two identical rings are stretched apart and the center film is popped. (Figure A). This catenoid is the simplest example of a minimum surface bounded by more than one closed curve. The sides of the catenoid, when viewed from the front, form catenary curves. As the rings are stretched apart, the curve of the sides sharpens until a critical point when the film joins at the waist and then separates and pulls back to cover each ring with a flat film. This separation always comes at a distance of 1.325 times the radius of the rings.

This classic catenoid invites further exploration. Instead of moving the rings directly in line with each other, keep them parallel and move them sideways (Figure C). Try using two rings with different diameters. Can you predict what shape soap film will form? Try using three rings instead of two (you will need someone to help). What will the soap film do?



GATEWAY ARCH

A well-known catenary curve in the United States is the Gateway Arch in St. Louis, Missouri. Designed by architect, Eero Saarin, it stands 192 meters (630) feet) high, the tallest monument in the country. Elevators inside the arch carry people to an observation deck. It is part of the Jefferson National Expansion Memorial built in honor of Thomas Jefferson's purchase of the Louisiana Territory from France in 1803. Standing next to the Mississippi River, the arch symbolizes the gateway to the west.

THUMBTACK SANDWICH I

I. Topic Area

Minimum surfaces — Steiner's problem

II. Introductory Statement

Students will find the shortest path connecting three points using soap film.

III.

Math Skills	Science Processes
a. Measuring length	a. Predicting
b. Adding	b. Observing
	c. Measuring & comparing
	d. Collecting & recording data

IV. Materials

Per group:
  - 3 thumbtacks or rivets of similar height (check hardware stores)
  - 2 plexiglass or glass plates about 10 centimeters square (4 inches square)
  - soap solution
  - shallow container larger than the glass plates
  - metric ruler
  - compass (optional)

masking tape
salt (optional)

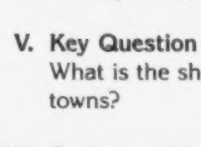
V. Key Question

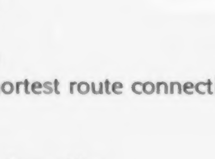
What is the shortest route connecting these three towns?

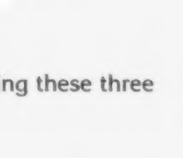
VI. Background Information

Early in the nineteenth century, Jacob Steiner, a mathematician at the University of Berlin, explored the minimum distances between a given number of points. This is the first of three activities which deal with the questions he raised and are collectively known as Steiner's problem. In the 1940's, Richard Courant popularized the use of soap films to find the answers.

When three points are at the vertices of an equilateral triangle, the shortest path connecting them meets in the middle at 120 degree angles (a). Example (a) has 58% and example (b) has 67% of the length of (c). Soap films will always form the minimum surface, providing a nice way to find the answer. See the fact sheet, "Keep It To A Minimum".

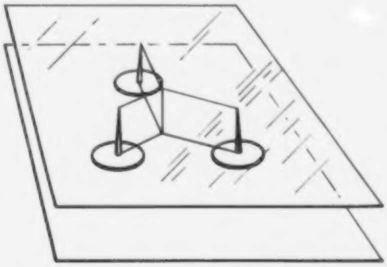

(a)


(b)


(c)

VII. Management Suggestions

1. The gathering of materials takes some perseverance but, once done, they can be used for several investigations and saved from year to year. Glass companies and hardware stores carry glass and plexiglass which can be cut for your needs. Plexiglass scratches more easily but is safer.
2. Depending on the number of sets obtained, this activity can be done by groups consecutively or simultaneously by the whole class, divided into groups of 2-4.



3. To make the thumbtack sandwich, have students place one plate over the activity sheet and mark each point with a tiny piece of masking tape. Place the thumbtacks on the tape and top with the other plate.
4. When looking at soap film pathways, foam can be a problem. Sprinkling salt on the foamy surface helps some but lifting the thumbtack sandwich out at an angle increases the chance of obtaining a clear answer. Keep the plates pressed together; if a thumbtack loses contact with the top surface, the pathway will be lost.
5. As with all soap film activities, recognize that recording data can be a bit awkward with wet hands. Someone other than the "dipper" should do the recording.
6. Encourage careful measuring because the soap film answer can be close to other possibilities.
7. This activity will take about 45 minutes.

VIII. Procedure

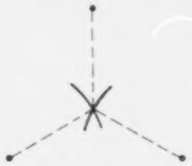
What the Teacher will do:

1. Present the scenario at the top of the page.

What the Students will do:

2. Draw three predicted road patterns using rulers.
3. Measure the paths they drew and record the totals.
4. Circle the smallest total.
5. Make a thumbtack sandwich and dip it in the soap solution.
6. Put the ruler on the top glass plate to measure the soap film path.

7. Record the soap film's total length and draw the path as accurately as possible. A suggestion: set a compass to the length of one of the soap film lines, then place it on the corresponding vertice on the activity sheet and draw a short arc near the center. Repeat this process for another soap film length. The intersection of these arcs is the point where the soap film meets. Once this point is found the lines can be drawn in accurately.



8. Draw a conclusion about the soap film's accuracy in finding the shortest path.

IX. Discussion Questions

1. Which path was shortest? (It should be the soap film because it always seeks the minimum. If not, the error is likely due to inaccurate drawings or measurements.) Describe the shortest path. (It meets in the middle.)
2. How does it compare with your predictions?
3. Which prediction made the longest route?

X. Extensions

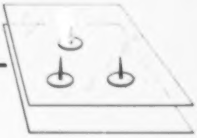
1. Using the length of the triangle's perimeter as 100%, figure the comparable percent of the soap film answer. For example, if the perimeter measures 78 millimeters and the soap film length is 45 millimeters, set up the ratio 45/78 and divide to find the percent. Figure the percents of other predictions.
2. Measure the soap film angles by placing a transparent protractor on top of the thumbtack sandwich.
3. Don't stop now. Do the related activities, "Thumbtack Sandwich II" and "A Fork in the Road".

Name______________

THUMBTACK SANDWICH I

Due to a volcanic eruption, lava covered large areas of the road between three towns. When the eruption was over and the lava had hardened, the town leaders agreed to rebuild the roads. Since cost depended on the road length, they wanted the shortest one possible. What is the shortest route connecting these three towns?

1) Draw three possible road patterns and measure to the nearest millimeter. Find the total lengths and circle the best prediction.



______ TOTAL

A

______ TOTAL

B

______ TOTAL

C

SOAP FILM

______ TOTAL

D

2) Using the town placement above arrange thumbtacks between glass plates and dip into soap solution. Record the soap film's total length. Then draw the results.

3) What did you learn? ______________________________

____

THUMBTACK SANDWICH II

I. Topic Area

Minimum surfaces — Steiner's problem

II. Introductory Statement

Students will use soap film to find the shortest road system connecting four towns.

III. Math Skills / Science Processes

Math Skills	Science Processes
a. Measuring length	a. Predicting
b. Adding	b. Observing
c. Sequencing	c. Measuring and comparing
	d. Collecting & recording data

IV. Materials

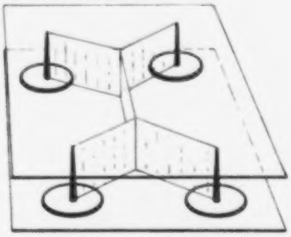
Per group:
- metric rulers
- 2 plexiglass or glass plates, 10 centimeters square (about 4 inches square)
- 4 thumbtacks or rivets of similar height
- soap solution in a shallow container

small county, state, or national outline map
county, state, or national road map

V. Key Question

What is the shortest route connecting these four towns?

VI. Background Information



This is a continuation of Steiner's problem, begun in "Thumbtack Sandwich I". From previous work, students should have an understanding that soap films take up a minimum amount of space. See the fact sheet, "Keep It To A Minimum". Soap films are sometimes used to help plan roads and other projects.

VII. Management Suggestions

1. Partners work well for this activity. If several sets of materials are not available, introduce to the class and partners can work consecutively. Everyone working at the same time is best.
2. It may take about 45 minutes for the first activity. The map activity will take an additional 45 minutes or more and can be done on a different day.
3. To make the thumbtack sandwich, have students place one plate over the activity sheet and mark each point with a tiny piece of masking tape. Place the thumbtacks on the tape and top with the other plate.
4. When looking at soap film pathways, foam can be a problem. Sprinkling salt on the foamy surface helps some but lifting the thumbtack sandwich out at an increases the chance of obtaining a clear answer. Keep the plates pressed together; if a thumbtack loses contact with the top surface, the pathway will be lost.
5. As with all soap film activities, recognize that recording data can be a bit awkward with wet hands. Someone other than the "dipper" should do the recording.
6. Encourage careful measuring because the totals can be close.

VIII. Procedure

What the Teacher will do:

1. Set up the situation by reading the first paragraph.

What the Students will do:

2. Draw a predicted path and circle the letter of the one that appears shortest.
3. Make a thumbtack sandwich, observe the soap film path, and draw it as best as possible.
4. Measure the pathways A through D (measure D by placing a ruler on top of the sandwich, not the drawing) and record the totals in the table.
5. Rank, by drawing, the four predictions from shortest to longest.

In the second activity, students will:

6. Use a map to compare real towns and roads to the shortest route possible, following the directions on the activity sheet. Put the map behind the second activity sheet and hold them up against a window. Record the placement of the cities chosen as dots in the blank area provided on the activity sheet.

IX. Discussion Questions

1. How did the different predictions compare? (B is the shortest, followed by A, then C. D's placement will vary with the individual drawings)
2. Did your experience with Thumbtack Sandwich I help you make a better prediction? How?
3. What other factors, besides length, do you think were considered when the roads were planned and built? (higher costs building through mountains, using mountain passes, avoiding large bodies of water, higher cost of building bridges over rivers and small lakes, buying right-of-way land, avoiding population centers, etc.)

X. Extended Activities

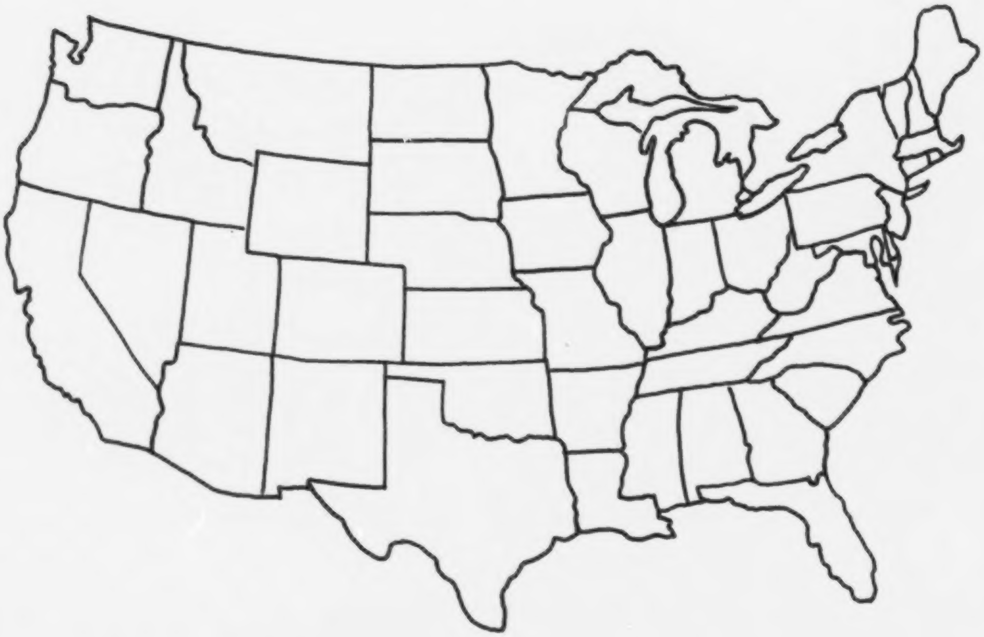
1. Measure the soap film angles by placing a transparent protractor over the sandwich.
2. Assign a cost per millimeter (such as $523). Use a calculator to figure the difference in costs for building each of the four roads.
3. Using the measure of the perimeter as 100%, figure the percent of the soap film pattern with ratios.
4. Continue exploring Steiner's problem by doing "A Fork in the Road".

XI. Curriculum Coordinates

Language Arts:

The opening paragraphs of the two "Thumbtack" activities present situations where finding a shorter route is desirable. Have students make up new scenarios. The following ideas have appeared in magazine articles: laying a natural gas pipeline, rebuilding roads after a central swamp dried up, and shoveling the shortest path through the snow.

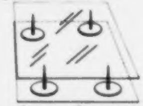
This map may be used for the second activity sheet. The teacher or students can plot the cities they wish and then test with soap film. Your own city can be included.



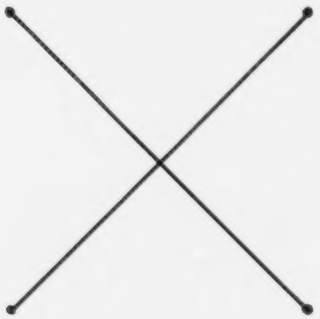
Name________________

THUMB TACK SANDWICH II

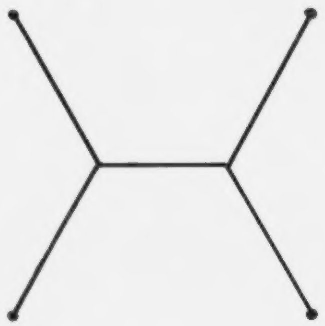
A cable television company just reached agreement to service four neighboring towns. To keep installation costs down, they wanted to string the cable in the shortest way possible. What is the shortest route between these four towns?



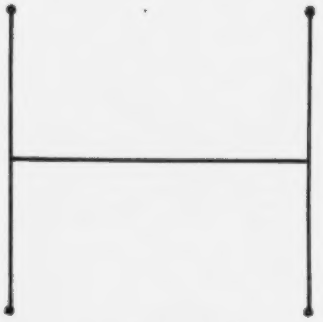
1) Add your own prediction to these possible routes. Circle the letter of the one that appears shortest. What answer does soap film give?



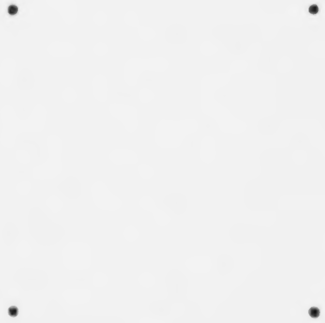
A



B



C



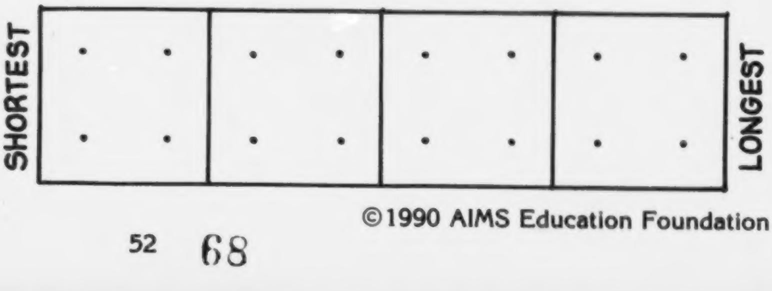
D

2) Measure the paths and find the totals.

LENGTH IN MM

A	
B	
C	
D	

3) Rank A through D from shortest to longest by drawing the paths below.



Name ______________________

THUMBTACK SANDWICH II

Pick three or more towns on a county, state, or national map. Mark and label their locations below. Find the shortest connection between them using soap film. Then compare the actual roads that were built.

What other factors, besides length, do you think were considered when the roads were planned and built?

A FORK IN THE ROAD

I. Topic Area

Minimum surfaces — Steiner's problem

II. Introductory Statement

Students will find the relationship between the number of points and the number of junctions in soap film pathways. They will also reach conclusions about soap film patterns and angles.

III. Math Skills

- a. Counting
- b. Measuring angles
- c. Comparing geometric figures
- d. Plotting coordinates
- e. Finding a formula

Science Processes

- a. Observing
- b. Measuring and comparing
- c. Collecting & recording data
- d. Interpreting data
- e. Applying & generalizing

IV. Materials

Per group:

2 plexiglass or glass plates, 10 centimeter square (4 inches square)
6 thumbtacks or rivets of similar height
transparent protractor
soap solution in container
masking tape
transparency of grid, optional (make from grid page included)

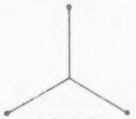
V. Key Question

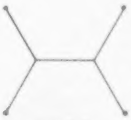
What patterns are created by the shortest road system connecting a given number of towns?

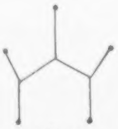
VI. Background Information

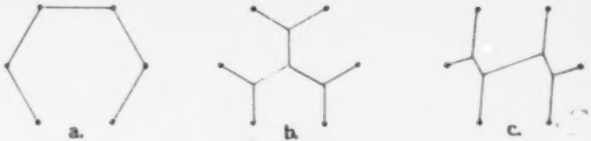
This activity is both a study of the various configurations for a given set of points and a comparison of different numbers of points. It continues the study of Steiner's problem begun in "Thumbtack Sandwich I and II". The more evidence that is collected, the more accurate the results. If soap film paths are formed with N number of points, there will be N-2 junctions. For example, nine points should yield seven junctions. Exceptions occur when the angles formed by the points are 120 degrees or greater because soap film always meets at 120 degree angles. The wider the angle, the closer the junction to the angle's vertex. See the fact sheet, "Nature's Patterns".

Here are soap film paths for some regular polygons:


triangle


square


pentagon


a. b. c.
hexagons

Note the unexpected results for the hexagon. There are three soap film answers but only one is the absolute minimum (a). The other two are called relative minimums and both are 4% longer than the absolute minimum. For any regular polygon with six or more sides, the absolute minimum is around the perimeter with one of the sides absent. This happens because the interior angles are 120 degrees or greater.

VII. Management Suggestions

1. This activity is extensive so decide on the option which best fits your needs. All options use the "Summary of Results" (first activity sheet) page.
   - a. Follow directions on the activity sheets for three towns, four towns, and five or more towns.
   - b. Use the grid sheet. Each group will need a transparency of one grid. The letter A under each grid instructs the students in thumbtack placement. The letter B is for students to determine their own figures and results. Either or both may be used.
   - c. Do an open-ended investigation of various numbers of points and record observations on the summary activity sheet. One way is to start with three points and keep moving one of the points. Observe the relationship of the junction to the vertices. Continue with four, etc.
2. Work in groups of 2–4. Depending on available materials, do at the same time or take turns.
3. This activity explores soap film pathways in some depth and will require at least 90 minutes. It can be divided into several lessons.

VIII. Procedure

For option (a), students will:

1. Identify the kinds of triangles from the arrangements of points for three towns (equilateral, isosceles, and right).
2. Use thumbtack sandwiches and soap solution to find the soap film pathways and record these as accurately as possible. Place one plexiglass square over the points on the worksheet and mark with a piece of masking tape. Put thumbtacks on these marks. A larger version of the points on the paper can also be made.
3. Count and record the number of soap film junctions. Measure the soap film angles with protractors to gain additional information.

4. Identify the kinds of quadrilaterals from the arrangements of points for four towns (square, rectangle, rhombus, parallelogram, and trapezoid).
5. Record the soap film results and count the junctions.
6. Experiment and record the connections between five points.
7. Find the three answers for the hexagon. (Hint: Try lifting the thumbtack sandwich out of the soap solution at different angles.) Attempt to determine which one is shortest.
8. Explore other sets of six or more points.
9. Summarize the collected data on the first page with the help of group and class discussion.

For option (b), students will:

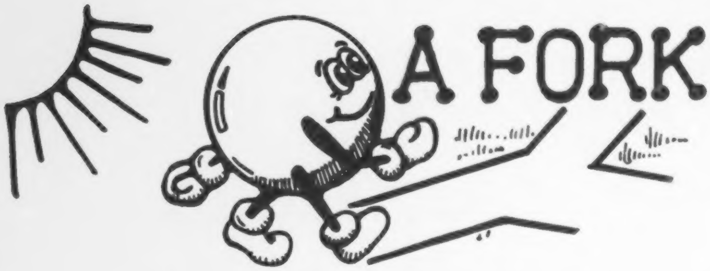
1. Place a piece of plexiglass over the grid and, with small pieces of masking tape, mark the coordinates given or ones of their own choosing. Always put the grid against the same corner of the plexiglass.
2. Dip in soap solution, place the transparent grid on the top piece of plexiglass in the same position as was used earlier. Record the coordinates of the intersection nearest each junction.
3. Draw the soap film pathway on the activity sheet grid, using the coordinates recorded.
4. Continue with the other grids, experimenting with 3, 4, 5, and 6-point figures.

IX. Discussion Questions

1. How are the number of points related to the number of junctions? (n-2, the number of towns minus two will give the number of junctions, but there are exceptions.) How many junctions would likely be formed by 24 points? (22)
2. When are there exceptions to this rule? (When the angle formed by the points is 120 degrees or more, the formula will not work. A set of points can have from 0 to a maximum of n-2 junctions.)
3. What happens to the position of the junctions as an angle increases? (The wider the angle, the closer the junction to the angle's vertex.)
4. What conclusion did you reach about the soap film angles? (They are always 120 degrees.)

X. Extended Activities

Explore the symmetry of the soap film paths.



A FORK IN THE ROAD

Name________________

What patterns are created by the shortest road system connecting a given number of towns?

SUMMARY OF RESULTS

# of towns	3	4	5	N
# of junctions				
angle measure				

1. How are the number of points related to the number of junctions?

____

____

2. When are there exceptions to this rule?

____

____

3. What happens to the position of the junctions as an angle increases?

____

____

4. What conclusion did you reach about the soap film angles?

____

____

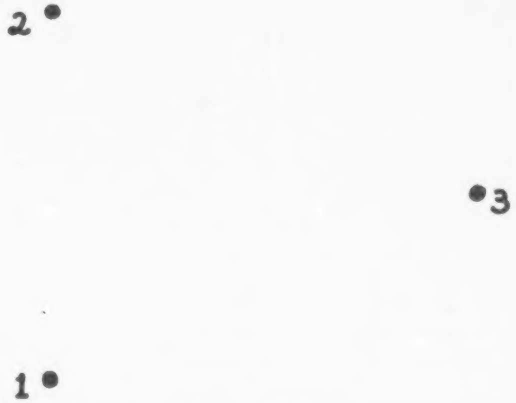
FORK IN THE ROAD

THREE TOWNS

Names ____________

____

Move thumbtack 3 each time to form a different arrangement of three points.

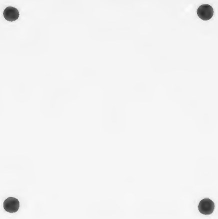
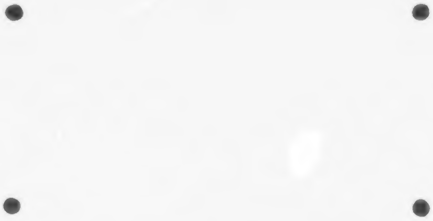
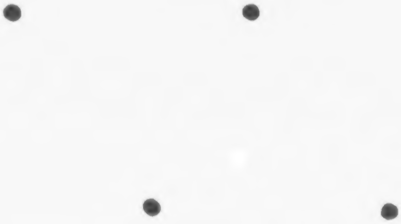
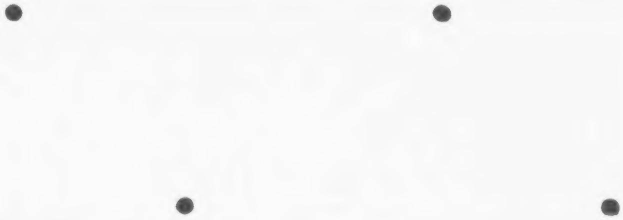
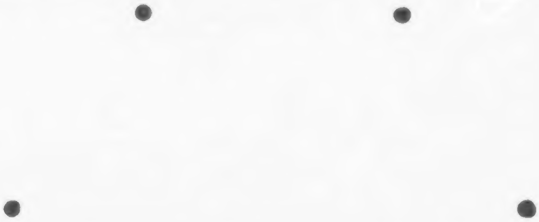
KIND OF TRIANGLE	ACTUAL SOAP FILM PATHWAY	# OF JUNCTIONS
		

FORK IN THE ROAD

FOUR TOWNS

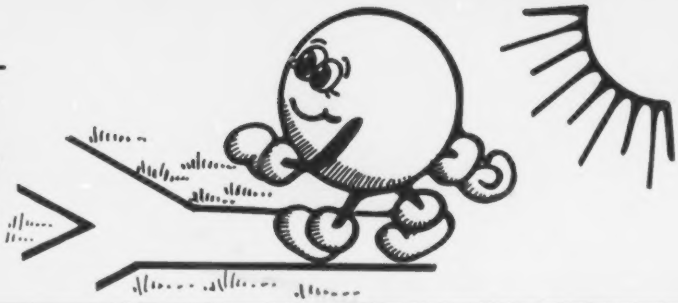
Names________________

____

KIND OF QUADRILATERAL	ACTUAL SOAP FILM PATHWAY	# OF JUNCTIONS
		
		
		
		
		

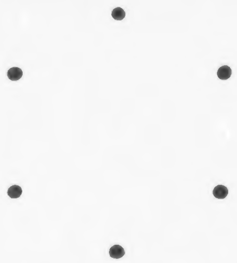
Name ________________

A FORK IN THE ROAD



KIND OF POLYGON	ACTUAL SOAP FILM PATHWAY	# OF JUNCTIONS
FIVE	OTHERS	
SIX		

The hexagon is a special case: Three different patterns are possible. Find and draw them.

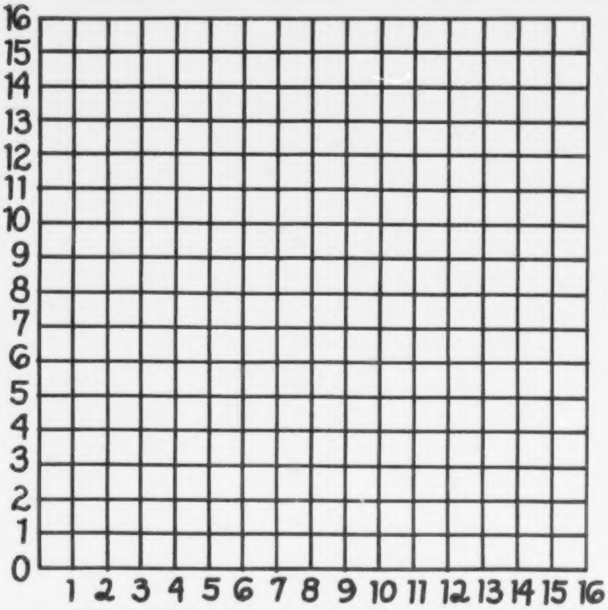


All the patterns form minimum surfaces. However, one formation is more minimum than the others! It is called the absolute minimum and the others are the relative minimums. Can you determine which one is the absolute minimum?

ADDITIONAL EXPLORATIONS:

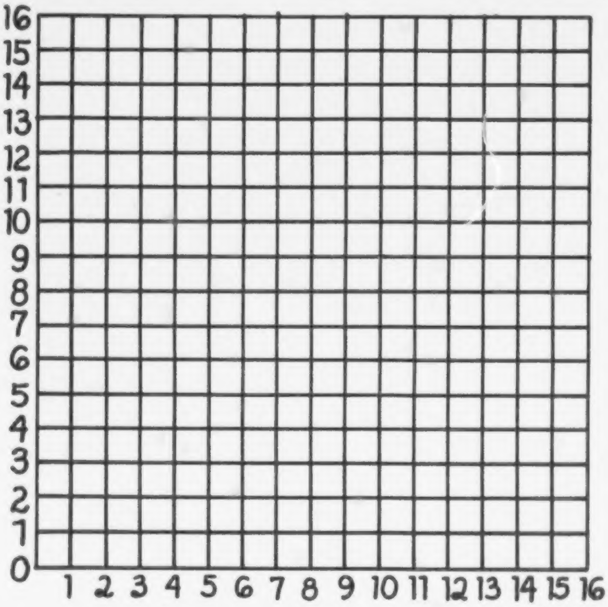
FORK IN THE ROAD

Names ______________
____


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

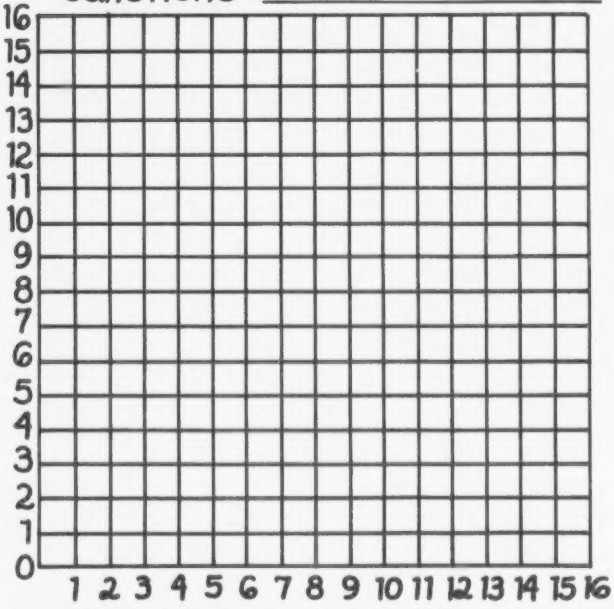
a. Thumbtacks: (2,3) (4,12) (14,7)
Junctions: ______________

b. Coordinates: ______________
Junctions: ______________


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

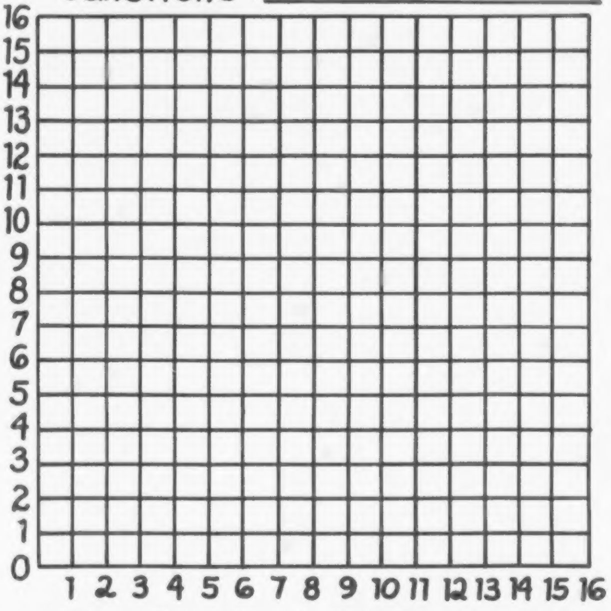
a. Thumbtacks: (2,2) (2,14) (11,14) (11,2)
Junctions: ______________

b. Coordinates: ______________
Junctions: ______________


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

a. Thumbtacks: (2,8) (6,14) (14,11) (13,4) (6,2)
Junctions: ______________

b. Coordinates: ______________
Junctions: ______________


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

a. Thumbtacks: (5,2) (2,8) (5,14) (12,14) (15,8) (12,2)
Junctions: ______________

b. Coordinates: ______________
Junctions: ______________

REFLECTIONS ON GEO-PANES

I. Topic Area

Minimum Surfaces — Plateau's problem

II. Introductory Statement

Students will find a formula relating the parts of polyhedrons and make discoveries about the soap film patterns which form inside them.

III. Math Skills

a. Studying the structure of polyhedrons
b. Counting
c. Finding a formula
d. Judging angles

Science Processes

a. Predicting
b. Observing
c. Collecting & recording data
d. Generalizing

IV. Materials

plasticine clay
round toothpicks, 3 or more boxes
soap solution and containers such as liter boxes, 1 per group
1 spool thread
cleanup—paper towels or bath towels, vinegar

V. Key Questions

1. How are the parts of these shapes related?
2. What kind of soap film patterns will form on these frames?

VI. Background Information

Historically, the problem of finding the minimum surface of a given closed boundary was posed back in the early nineteenth century by Joseph Plateau, a Belgian physicist. Soap films provide a simple way to solve Plateau's problem. It was not solved mathematically until the mid 1970's.

Plateau observed that three soap film surfaces come together to form a line and they always do so at 120 degree angles. He also found that four lines converge to form a point at angles slightly greater than 109 degrees, 109° 28′ 16″ to be precise. Following these rules, the soap film meets at the center of the frame rather than spanning the faces. It forms the minimum connecting surface. In this activity, these soap film patterns are called "geo-panes". See the fact sheet, "Keep It To A Minimum".

Polyhedron comes from two words. Poly means many. Hedron means sides. A polyhedron is a many-sided figure. The shapes shown in the first table are, from top to bottom: TETRAHEDRON, CUBE, TRIANGULAR PRISM, PYRAMID, PENTAGONAL PRISM, HEXAGONAL PRISM, OCTAGONAL PRISM, and OCTAHEDRON. Try others.

Vertices are the clay balls and can also be referred to as points. Edges are the toothpicks or line segments. Faces are the sides (which are the open flat surfaces of the toothpick polyhedrons).

The relationship of vertices, edges, and faces, first discovered by Leonhard Euler (pronounced "oiler") in the sixteenth century, can be stated in the following ways:

Vertices + Faces = Edges + 2
Vertices + Faces − 2 = Edges

This is called Euler's Theorem and is true for all convex, or outward-facing, polyhedrons. See the fact sheet, "Who's Euler?".

Two-dimensional shapes are flat. They have length and width only. Three-dimensional shapes have length, width, and height.

RESULTS

Shape	Vertices	Edges	Faces	# geo-panes
Tetrahedron	4	6	4	6
Cube	8	12	6	9
Triangular Prism	6	9	5	9*
Pyramid	5	8	5	9
Pentagonal Prism	10	15	7	11*
Hexagonal Prism	12	18	8	13*
Octagonal Prism	16	24	10	17*
Octahedron	6	12	8	varies

*Results for the prisms will vary depending on the length of the edges connecting the two triangles, pentagons, etc.

VII. Management Suggestions

1. Cut a piece of thread for each person, about 50 centimeters long.
2. This activity is best done during two different periods, one to find the formula and the other to work with the soap films. Each period may take 45 minutes or more.
3. Groups of 3–4 are recommended. Members need to decide who will build which shapes and then share a container as data is gathered.
4. Caution students to dip carefully so the water stays as free of bubbles as possible.
5. Toothpicks should be broken to make the more complex polyhedrons, otherwise their weight will cause them to fall apart.
6. To avoid temptation, do not have containers with soap solution near students until needed.
7. The thread should never be strung across two toothpicks as it will create another line segment and alter the results. Loop the thread around a single toothpick. Do not tie.
8. Cleanup: Clean as much as possible with towels. Then sprinkle with vinegar and wipe dry. It will cut through the soap film.
9. If more permanent, but still fragile, geo-panes are desired, use the recipe with gelatin in "Soap Solution Recipes".

VIII. Procedure

Day 1:

1. Discuss the meaning of polyhedron. Then ask the first key question.
2. Pass out clay, toothpicks, and thread.
3. Students will:
   - a. Divide responsibilities for building the polyhedrons shown in the table.
   - b. Build the shapes and complete the table with the teacher's guidance as needed.
   - c. Look for the relationship between vertices, edges, and faces and state as a formula.
4. Allow enough time for students to discover the pattern and let them continue to work on it at home if needed.
5. Have groups save their structures by placing them on a piece of paper and signing their names.
6. When the discovery has been made, ask the groups to report their formulas. Talk about Euler.

Day 2:

1. Decide where the dipping is to be done. Cover the area with newspaper or butcher paper if appropriate.
2. Have groups retrieve their polyhedrons.
3. Make a flat clay and toothpick triangle. Hang it from a thread and dip into the soap solution. Explain that, for our purposes, the resulting pane will be called a geo-pane.
4. Pose the second key question. Have students orally predict where the soap film will form. (Example: cover the faces, toward the center, etc.)
5. Students will:
   - a. Dip their polyhedrons in the soap solution and draw the results for the tetrahedron and cube, adding a third one of their own choosing.
   - b. Observe the joining of surfaces and lines and answer the questions in section 4.
6. Lead a class discussion on minimum surfaces to answer why this happens.

IX. Discussion Questions

1. How are the parts of these shapes related? (Edges = Vertices + Faces – 2)
2. Why did the geo-panes form this way? (Soap films always seek the minimum surface. The system of panes which meet in the center of the polyhedron take up less surface area than any other arrangement.)
3. How many surfaces come together to form a line? (3) At what angle do these surfaces join? (120 degrees)
4. How many lines come together at a point? (4) How do the angles of the lines at a point compare to a right angle? (greater than) to the angle in the previous question? (less than) By observation, how many degrees do you think the angles have? (The actual measurement is slightly more than 109 degrees.)
5. Is the geo-pane pattern the same each time? (Usually, but a change in conditions such as wind or bubbles can alter the pattern.)
6. How can you change the geo-pane pattern? (Pop a pane, blow on it, partially submerge the polyhedron, etc.)
7. Which geo-pane pattern did you like best?

X. Extended Activities

1. Count the number of geo-panes formed on each frame. Only one side of each pane should be counted. Several dips may be needed to confirm results. Is there a relationship between the number of geo-panes and vertices, edges, or faces? (Partially. Some of the prisms have one more geo-pane than the number of vertices, but this will vary depending on the way the prism is constructed.)
2. Make wire frames and explore other shapes such as curved ones. Instructions and suggestions are included in this book.
3. Observe how bubbles pack together. Put a little soap solution in a clear quart jar. Wet the sides and, with a straw, blow bubbles until it is nearly full. There should be many examples of converging surfaces and lines which illustrate Plateau's findings. Bubbles will not form uniformly when packed together, but it can be observed that an average bubble will have 5 to 6 edges per face, 13 to 14 faces, and 22 to 23 corners. See the fact sheet, "Nature's Patterns".

XI. Curriculum Coordinates

Art:

Make paper polyhedrons. See "Polyhedron Models". Decorate them and hang them in the room or on a Christmas tree. This is also good as a preliminary activity. Helpful books on this subect are:

Polyhedron Models for the Classroom by Magnus J. Wenninger (National Council of Teachers of Mathematics [NCTM])

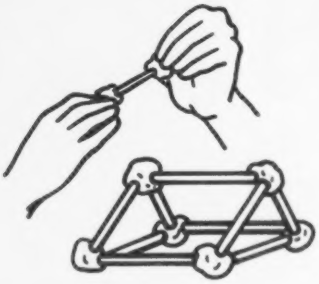
Paper Folding for the Mathematics Class by Donovan A. Johnson (NCTM)

A First Book of Space Form Making by George R. Fouke (GeoBooks)

Computer:

Create 3-D geometric figures using Logo.

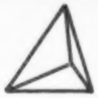
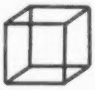
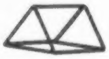
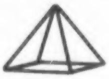
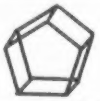
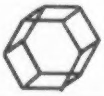
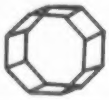
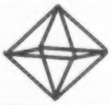
Name ____________________



REFLECTIONS ON GEO-PANES

How are the parts of these shapes related?

① Build these shapes with toothpicks and clay. Fill in the chart.

name	shape	# of vertices	# of edges	# of faces
				
				
				
				
				
				
				
				

② Look for a pattern relating vertices, edges and faces.

State the formula: ____________________________________

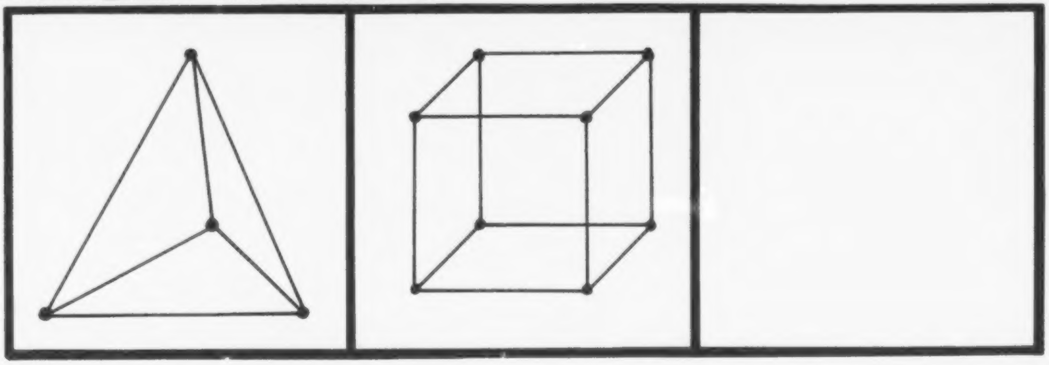
This is called Euler's (pronounced "oilers") Theorem.

REFLECTIONS ON GEO-PANES

"Plateau's Problem"

What kind of soap film patterns will form on these frames?

③ Hang shapes from a thread and dip them completely into soapy water. Draw the results.



④ Discover what Joseph Plateau, a 19th century scientist, learned about soap film patterns:

ⓐ Why did the geo-panes form this way?

____

____

ⓑ How many surfaces come together to form a line? __________

Guess the angle at which these surfaces join. __________

ⓒ How many lines come together at a point? __________

How do the angles of the lines at a point compare to a right angle? __________

To the angle you guessed in 4-b? __________

⑤ What if...

—you poked out a pane with your finger?

—you captured a bubble as the frame is removed from the water?

—you tried some curved shapes?

WHO'S EULER ?

Leonard Euler (pronounced "oiler") was one of the world's great mathematicians. In all of history, no one has written more about mathematics. Although German was his native language, he wrote in Latin, German, and French. His collection of some 32 books and some 700 articles are expected to fill 74-75 volumes now being printed, the result of 60 years of scientific studies. Euler's writings averaged 800 pages a year. He wrote on all levels, from math textbooks for Russian elementary schools to articles which have changed the way college mathematics is taught today. No one has surpassed him in his special field, analysis.

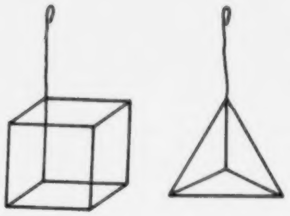
Euler was born in Basel, Switzerland on April 15, 1707. His father was a Protestant minister and Euler remained religious throughout his life. He grew up studying mathematics, theology, medicine, astronomy, physics, and oriental languages. One of his teachers was John Bernoulli of the famous Bernoulli family and Euler was a friend of his sons Daniel and Nicholas. Daniel developed the Bernoulli principle. Euler received a master's degree at age seventeen. Later he married and raised thirteen children. All but five died very young.

In the eighteenth century, the royal academies were the centers of research in Europe, supported by interested rulers. Catherine I invited him to St. Petersburg Academy in Russia. He was a professor of physics and math there, after starting out in medicine. Later he worked under Frederick the Great at the Academy of Sciences in Berlin for 25 years. At Catherine the Great's request, he then returned to Russia. In his work at the academies, Euler was free to explore his interests rather than solve practical problems for the rulers.

Euler could work anywhere under any conditions, often with a baby in his lap and children playing around him. He had a great memory and his mind was excellent at mental computation.

In 1735 he lost the use of his right eye. A cataract completely clouded his other eye by 1771. As his blindness increased, he wrote formulas with chalk on a large slate. Eventually he had to dictate his ideas to his sons. He died September 18, 1783, while sipping tea and visiting with one of his grandchildren. At the time he was calculating the orbit of the newly discovered planet, Uranus.

WIRE FRAMES



This project is intended for teachers who want a permanent set of frames, but may be used with capable students.

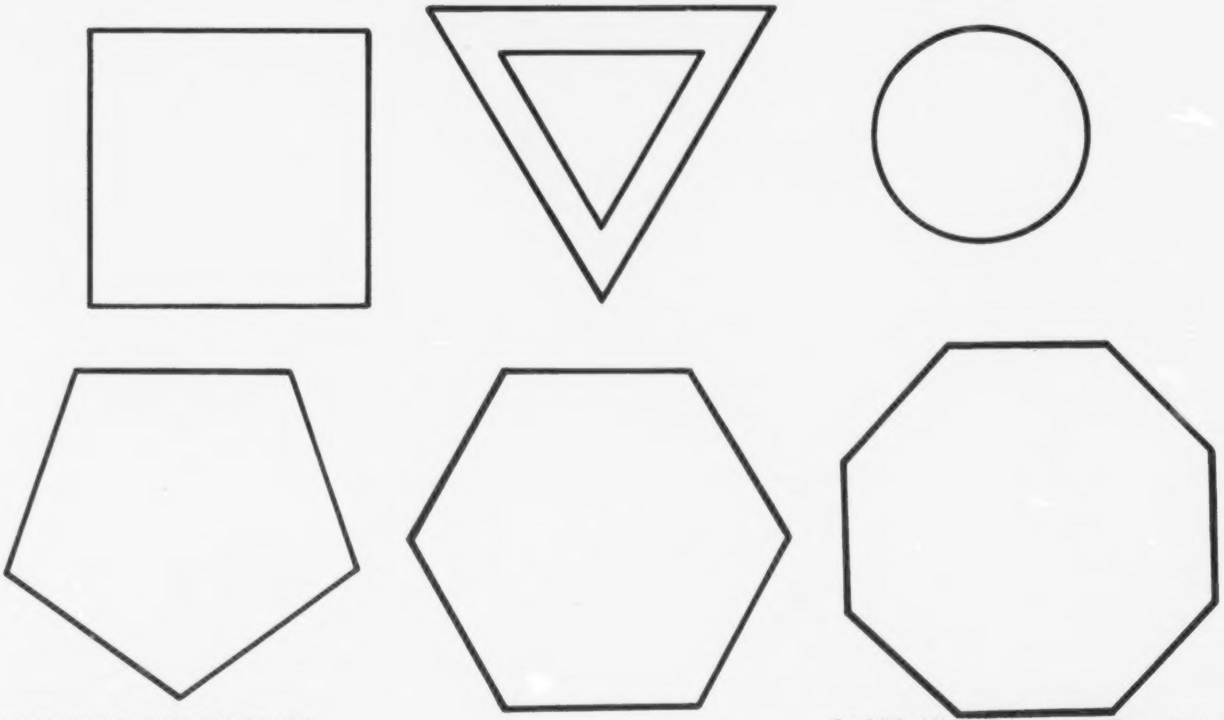
MATERIALS:
- soldering iron
- solder
- wire stripper/cutter
- pliers
- 18 or 20 gauge solid core copper wire

SAFETY:
1. Students should work only under adult supervision.
2. Clear the work area and choose a heat resistant work
3. Use pliers while applying solder; the wires conduct heat.

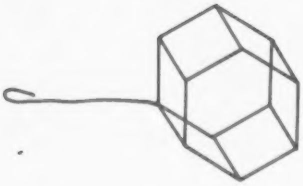
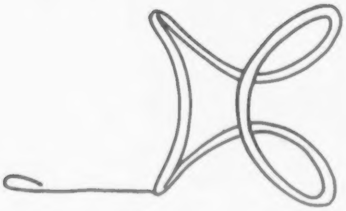
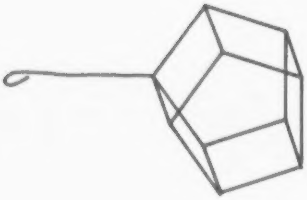
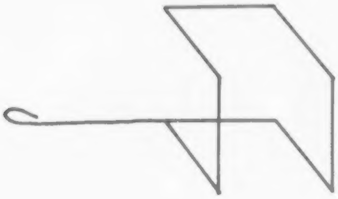
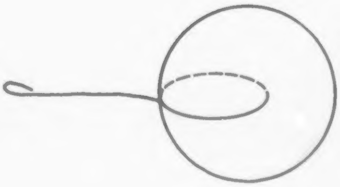
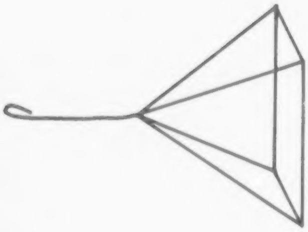
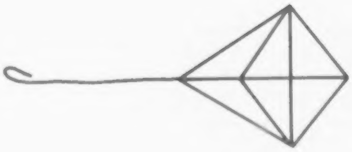
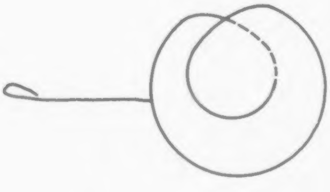
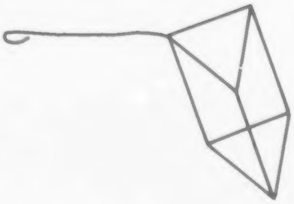
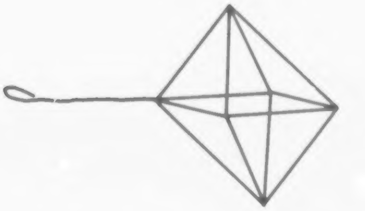
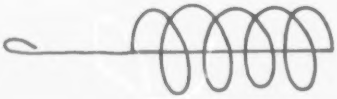
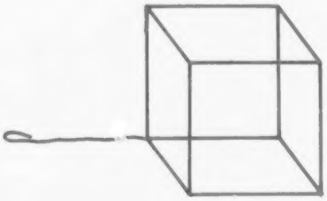
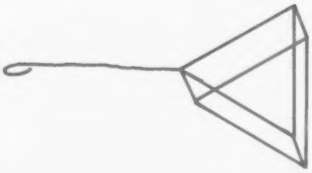
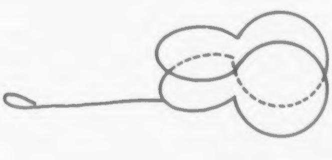
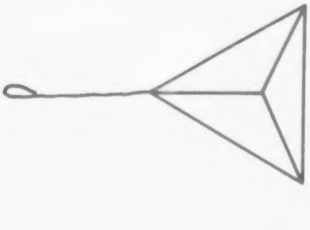
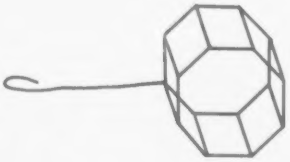
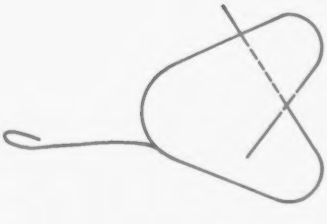
INSTRUCTIONS:
1. Strip the wire if needed. Lay a wire on the base pattern desired and bend into shape with pliers.
2. Hold solder next to the wire joint and apply the heated iron. Solder can also be melted on the tip of the iron and applied to the joint. If needed, recruit the help of another person.
3. Be sure to include a handle on the finished product.

DISPLAY: Frames can be strung on a piece of wire or, if the handles are strong enough, put into a vase forming a bouquet. Either form of display is likely to stimulate curiosity.

BASE PATTERNS: If desired, duplicate on tagboard and laminate.

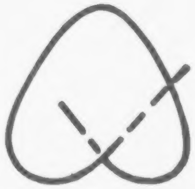


FRAME IDEAS

SPECIAL
SOAP FILMS

OPEN CURVE

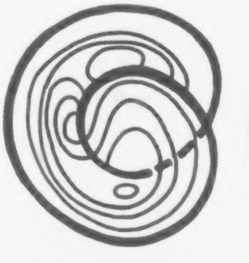


Soap films normally form across a defined hole, a closed curve. This frame supports a soap film even though it has two free ends, an unusual occurence.

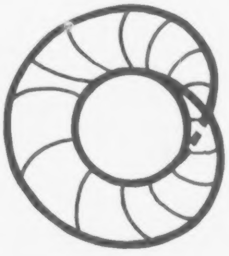
MOEBIUS STRIP

If the spacing is properly shaped between the two circular areas, a one-sided film surface will form. It has no top or bottom, nor front or back. This is an example of a Moebius strip, named after August Moebius. The German mathematician and astronomer discovered it in 1858.

By changing the spacing, a two-sided surface forms.



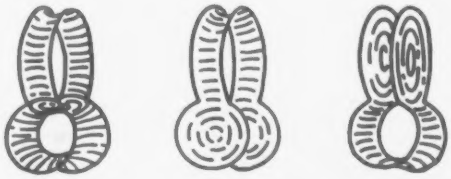
2 sides



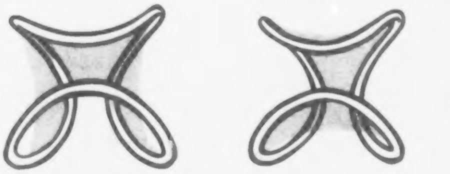
1 side

DIVERGENT FRAMES

A.



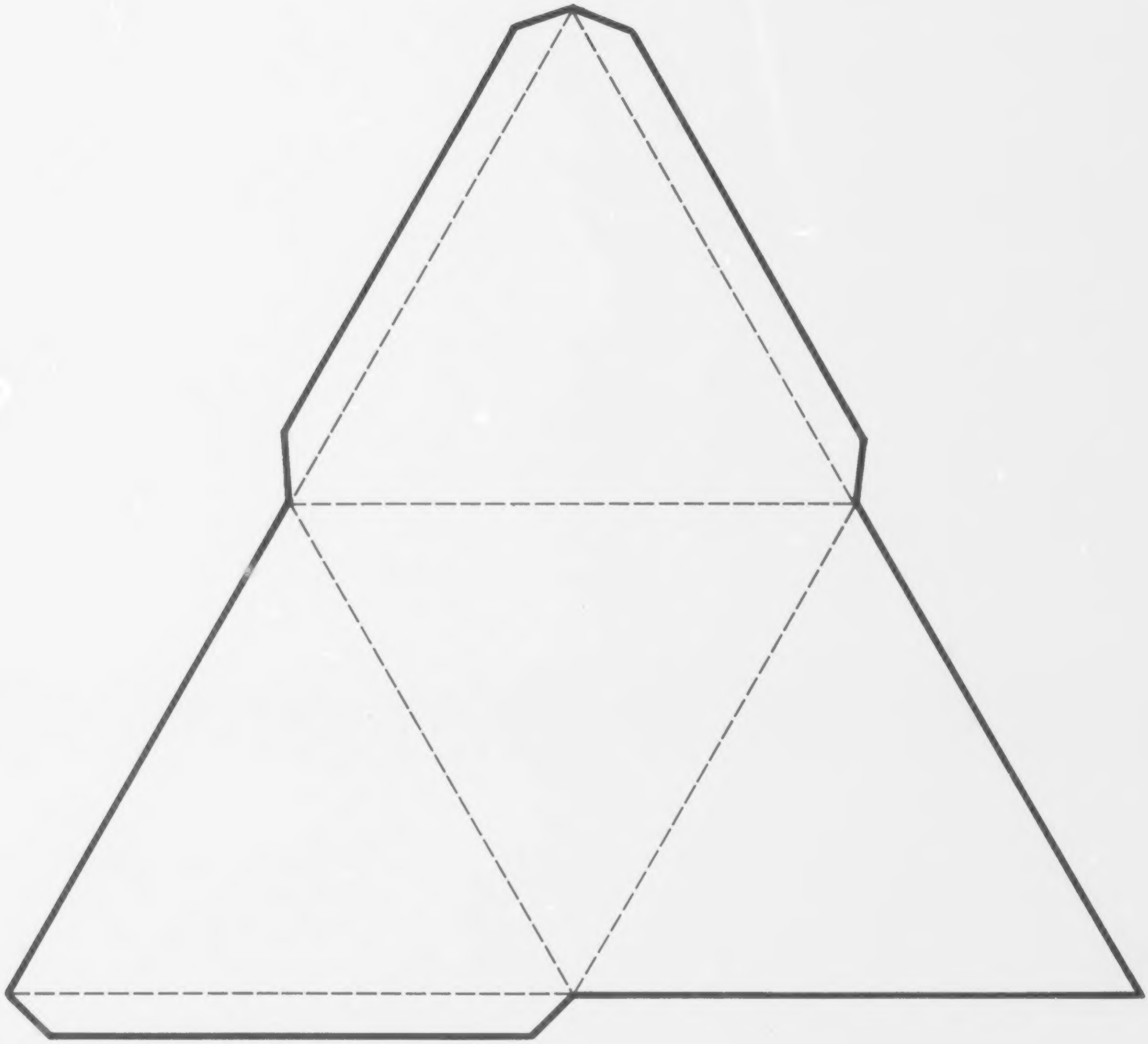
B.



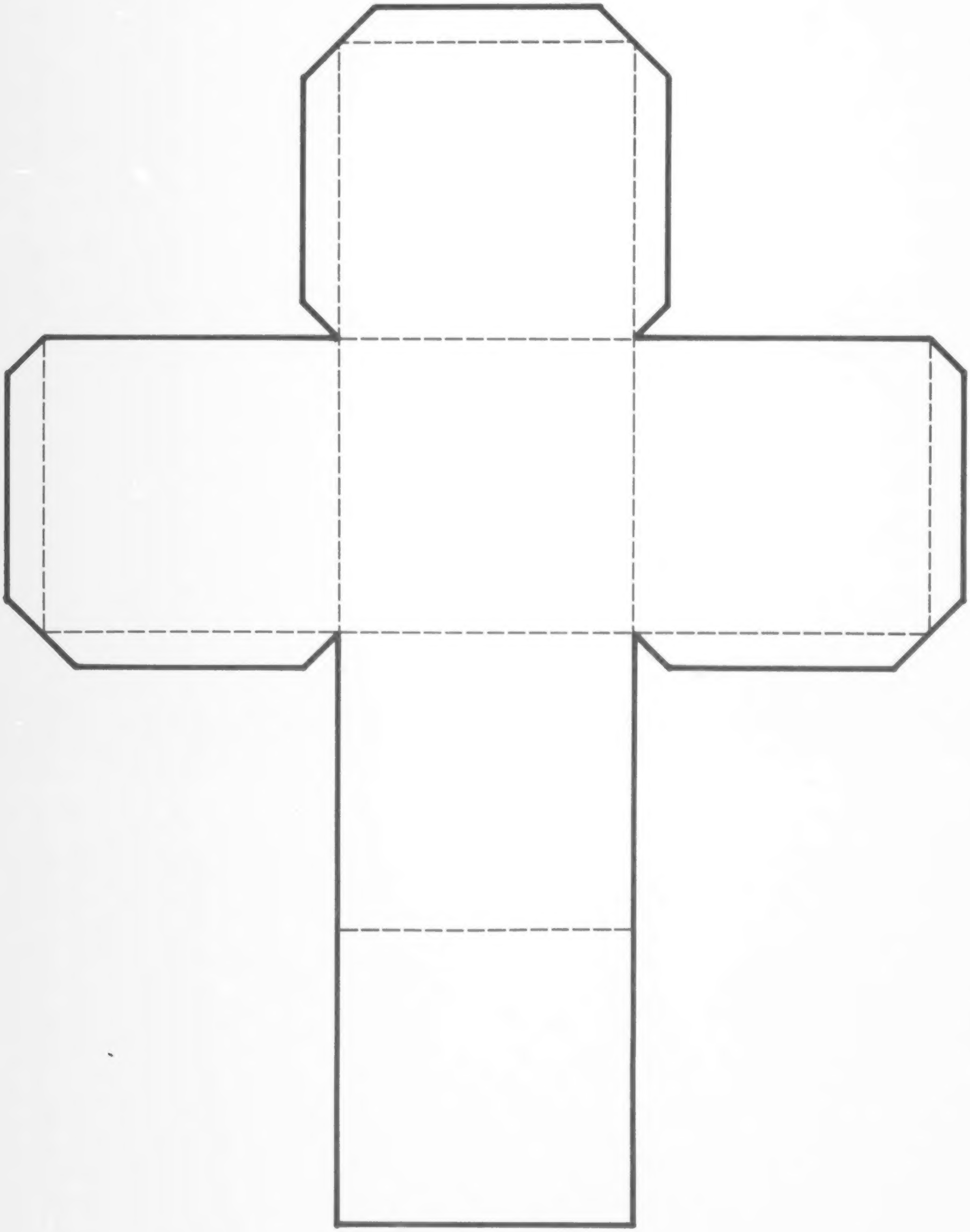
Depending on how this frame (A) is removed from the soapy water and on the spacing between the wires, three different minimal film surfaces can be made. Two different films can be formed on the other frame (B).

Try creating another structure that forms films in more than one way.

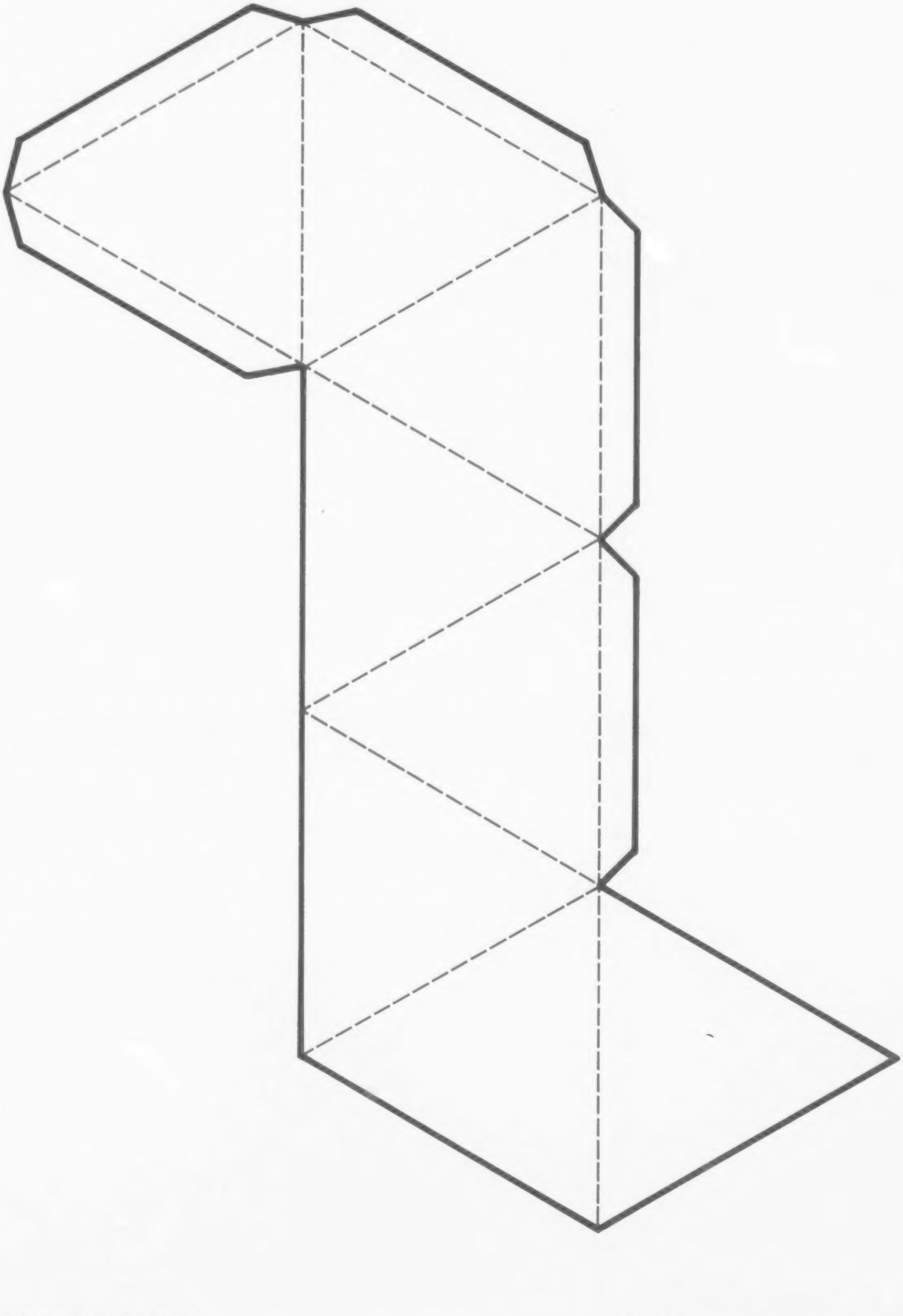
TETRAHEDON
MODEL



HEXAHEDRON OR CUBE MODEL



OCTAHEDRON MODEL



UNDER PRESSURE

I. Topic Area
Air pressure

II. Introductory Statement
Students will observe that small soap bubbles have greater internal air pressure than large ones.

III. Math Skills	**Science Processes**
a. Constructing with a compass and protractor	a. Making and testing hypotheses
	b. Observing
	c. Comparing
	d. Collecting and recording data
	e. Generalizing

IV. Materials
Per person:
  2 straws
  compass and protractor
  scissors
  blank sheet of paper
  about a cubic centimeter of clay
several blank overhead transparencies, clear glass pie plates, or plexiglass sheets
soap solution in containers
rags or old towels for cleanup

V. Key Question
How does the air pressure inside large and small bubbles compare?

VI. Background Information
There is greater air pressure inside a small bubble than a large one. See the fact sheet, "Air Pressure".

Part 2 of this activity provides for compass and protractor work to construct the wall joining two bubble hemispheres. This is then tested with bubbles. There is also a way to construct the walls for three intersecting bubbles. It is not included here because of its complexity.

VII. Management Suggestions
1. Flat desks or a large table are suitable for blowing hemispheres. A dry area of the room should be set apart for writing.
2. Each student should complete all the activities but encourage them to confer with each other.
3. Two or three periods are suggested. Do Part 1 and 2 for the first lesson (about 60 minutes) and Part 3 (about 45 minutes) for the second lesson or divide into three parts.

VIII. Procedure
What the Students will do:
1. Respond to the key question with a hypothesis.
2. Follow the directions for observing hemispheres. To blow hemispheres, dip a straw in soap solution, touch it to the wet surface at an angle, and blow gently.
3. Use a protractor and compass to construct the wall between two bubbles. A teacher-guided, total class lesson is recommended for this section. All constructions should not be the same size.
4. Test their constructions by blowing bubble hemispheres on top of them. Any flat, transparent surface can be used. Expect the bubbles to slide around some; they are hard to train.
5. Construct and use the double bubble blower. Bubbles won't slip off the ends as easily if the blower is held vertically. Gravity does not affect the results.
6. Write their observations and conclusions, followed by a class discussion.

IX. Discussion Questions
1. Describe your observations of the bubble walls in the hemispheres. (The wall is flat when the bubbles are equal because there is equal pressure on both sides of the wall. For two unequal bubbles, the small bubble curves into the large one. The small one is exerting more pressure.)
2. Did your construction match the hemisphere?
3. What did you observe with the double bubble blower? (The air in the smaller bubble pushed into the larger one, making it bigger. This happens no matter which way it is held.)
4. What is your conclusion? (There is more air pressure inside smaller bubbles.) How can this be explained? (For Part 1 and 2, the bubble that pushes into the other one has greater air pressure. See the fact sheet, "Air Pressure". For Part 3, the bubble with greater air pressure will have more push. The air pressure in the small bubble flowed into the other one to equalize the pressure throughout the closed space.)

X. Extended Activities
Devise another way to show the differences in air pressure between large and small bubbles.

Name ____________________

UNDER PRESSURE

How does the air pressure inside large and small bubbles compare ?

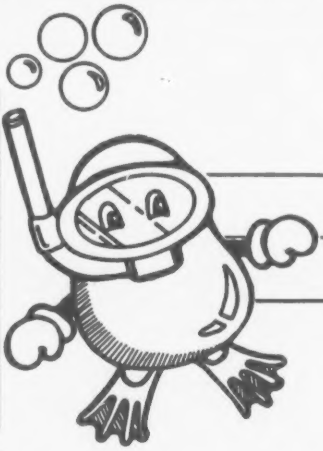
HYPOTHESIS:

____

____

PART 1

On a flat, wet surface, blow two bubbles joined together. Look at the wall between them. Draw and describe your observations.



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____

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TOP VIEW OF TWO BUBBLES, SAME SIZE

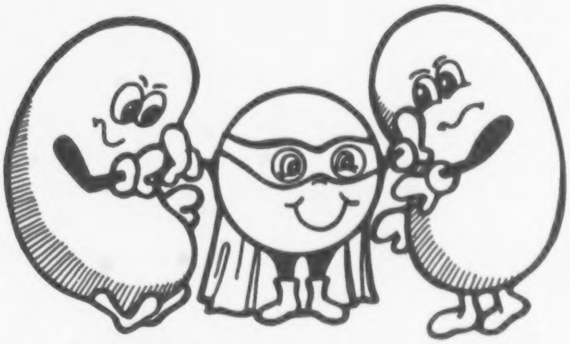
____

____

____

TOP VIEW OF TWO BUBBLES, DIFFERENT SIZES

____

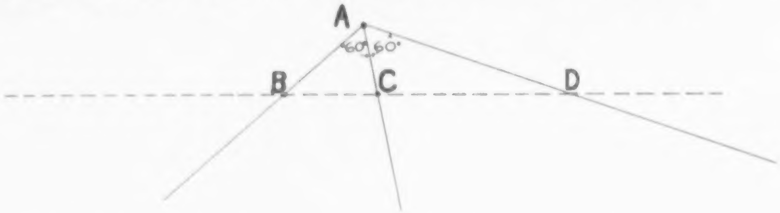


UNDER PRESSURE

Here is a way to determine the kind of wall that will form between any two bubble hemispheres. Draw one on another paper and test it.

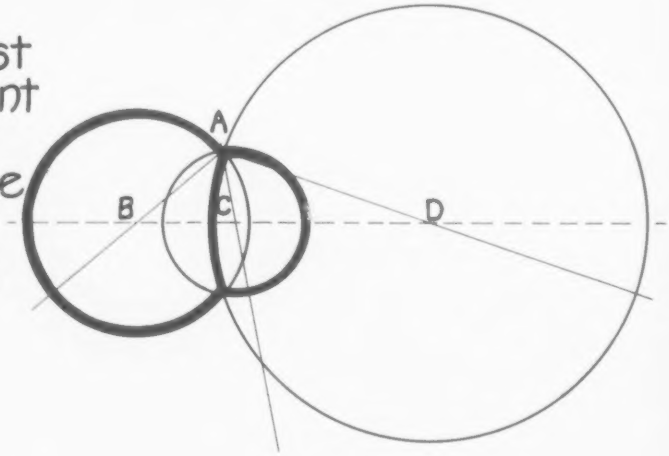
PART 2 CONSTRUCTION

① Make a dot and label it A. Draw three rays from A, forming 60° angles. Draw a line intersecting all three lines. Label these intersections B, C, and D, as shown below.



② Draw three circles, placing the compass point on each intersection (B, C, and D) and using the distance to A as the radius.

③ Darken the arc of the largest circle from A to the other point where it intersects the two smaller circles. This shows the position of the wall of two adjoining bubbles. Darken the two smaller circles to the endpoints of this arc. These are the two bubbles.



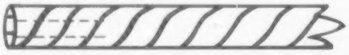
④ Put a transparency or glass dish over your drawing, wet the surface with soapy water, and blow bubbles the size of those drawn. Does the wall between the two bubbles have the same curve as the one you constructed?______

Name ______________________

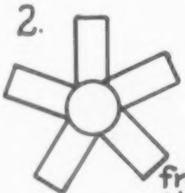
UNDER PRESSURE

PART 3 DOUBLE BUBBLE BLOWER

BUILD: ① Cut a straw in half. Make at least four slits, 1½ - 2 cm long, in each end of one piece.

1. 

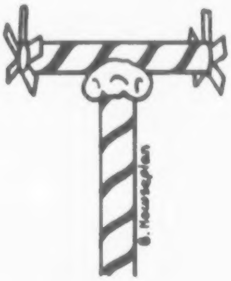
② Bend these slits back.

2. 

front view

③ Cut a hole, smaller than the straw's diameter, in the center of the same piece.

④ Insert the other straw piece and seal any spaces with clay.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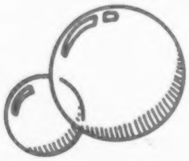


USE: Dip each fanned end into the soapy water and blow from the bottom of the T. Pinch the end of the straw to keep in the air. Observe what happens to the bubble on each end. Try it several times.

OBSERVATIONS: ____

____

____

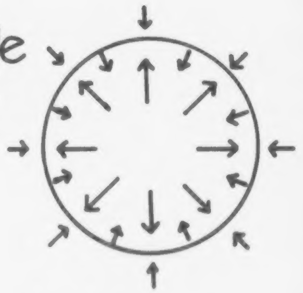
CONCLUSIONS: ____

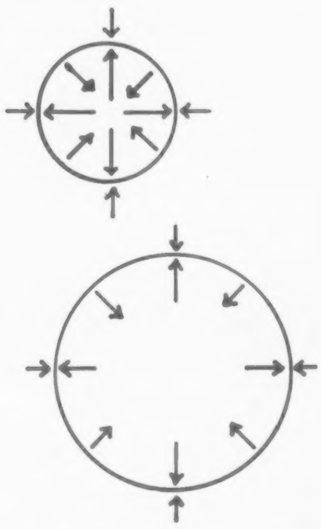
____

____

AIR PRESSURE IN BUBBLES

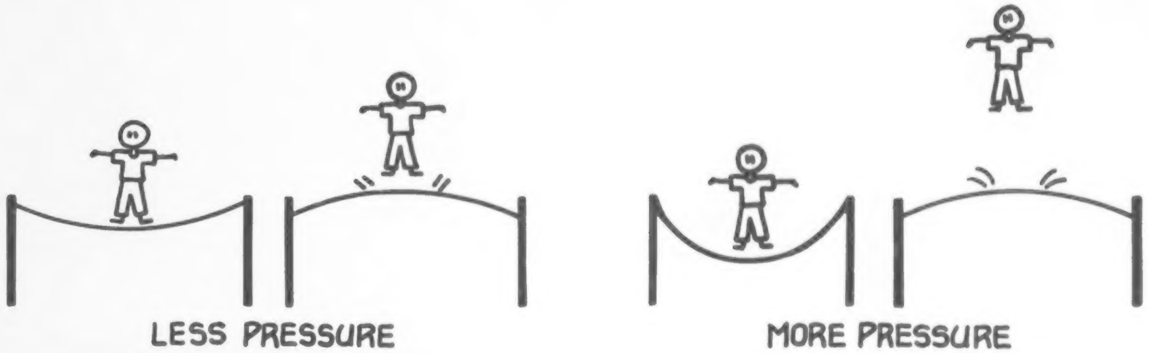
There are several forces acting on a bubble. The internal air pressure pushes out against the bubble while atmospheric pressure pushes in. The surface tension of the bubble, which is caused by cohesion between the water molecules in the soap film, creates a force that acts in toward the center of the bubble. The forces acting on a stable bubble are in equilibrium. The force of the internal air pressure pushing out on the bubble is equal to the combined inward force of the atmospheric pressure and the surface tension.



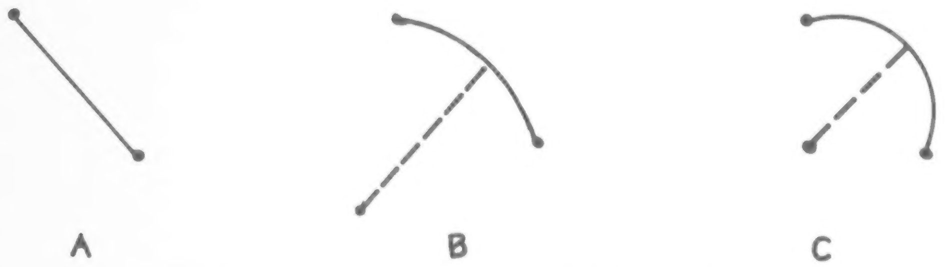


The inward force caused by a bubble's surface tension varies with its radius of curvature (its radius). This force is greater for bubbles with smaller radii of curvature. There is a corresponding greater internal pressure in small bubbles to counteract this greater inward force. While this is easy to prove mathematically and its effects are easily seen by doing the following activities, it seems to go against common sense.

Comparing this concept (about the internal pressure differences in different sized bubbles) to blowing up a balloon might help. A balloon is harder to inflate when it is small and has a small radius of curvature. As it gets larger, its radius of curvature increases and it is easier to blow up.

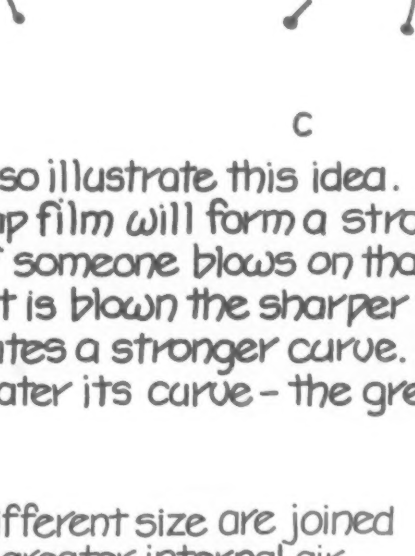


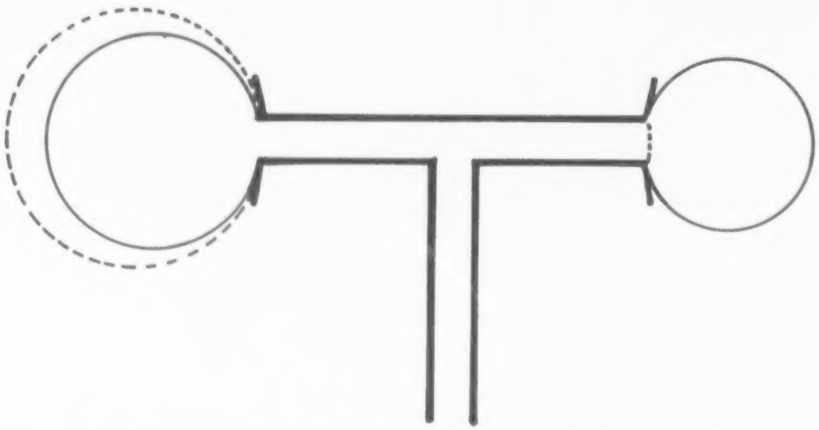
Another comparison can be made to a person on a trampoline. When the feet hit the trampoline from a short height, there is light pressure and it creates a slight curve. Bouncing from a higher position causes greater pressure and a sharper curve.



Two tacks between glass plates also illustrate this idea. If it is dipped in soap solution, the soap film will form a straight line between the two tacks (A). If someone blows on that film, it starts to curve (B). The harder it is blown the sharper the curve (C). Greater air pressure creates a stronger curve. The smaller the bubble's radius – the greater its curve – the greater the air pressure inside it.

When two bubble hemispheres of different size are joined together, the smaller one, which has greater internal air pressure, will push into the larger one. This is evident by looking at the wall that connects the two hemispheres. It bends in toward the larger bubble.





The solid lines show the bubbles when first blown. The dotted lines represent the shape of the soap film after it becomes stable.

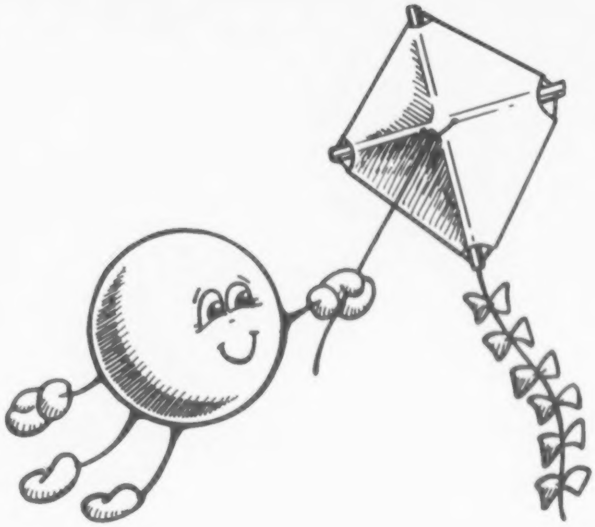
When two bubbles are blown with a straw "T" and the bottom straw is sealed, air passes freely between the two bubbles and their internal pressures will equalize. Since air pressure is greater in small bubbles, air will flow from the smaller bubble into the larger one, decreasing the smaller bubble while increasing the size of the larger one. This will continue until there is no bubble left on the one side; only a small, slightly bulging, soap film covering the open end of the straw. The bubble and straw system is now in equilibrium.

If the small film were placed on the open part of the large bubble it would fit almost exactly. There would be a minor difference due to the volume of air inside the straws. The two soap films are actually two surfaces of a single bubble connected by the straw "T" and together they form the least possible surface area for the volume of air enclosed.

Thus, we can see that while common sense might try to tell us that there is greater air pressure inside large bubbles because they contain more air, in reality exactly the opposite is true.

Name ____________________

BUBBLES ALOFT



Materials: bubble tool
soap solution

Procedure:

1. Blow a bubble and find a way to keep it in the air without touching it.

   What worked? ________________________________

2. Try this coded suggestion:

25-3-24-7 1-17-23-20 10-3-16-6 17-20 3 5-3-20-6

4-3-5-13 3-16-6 8-17-20-22-10 3-4-17-24-7 22-10-7

4-23-4-4-14-7.

A	B	C	D	E	F	G	H	I	J	K	L	M
3	4	5										

N	O	P	Q	R	S	T	U	V	W	X	Y	Z

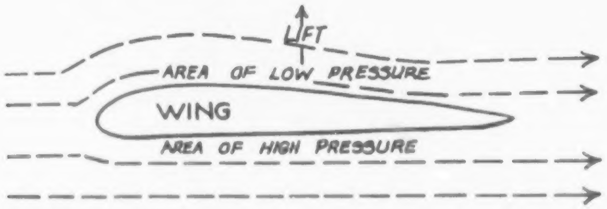
BUBBLES ALOFT

FACTS

Background:

Bernoulli's principle states that the higher the speed of a flowing liquid or gas, the lower the pressure. As the speed decreases, the pressure increases.

An airplane illustrates this. When air meets the front of a wing, some goes under and some goes over it. The air meets at the same time at the back of the wing. Because of the wing's structure, the air above the wing has to travel farther and, therefore, faster. This lowers the air pressure. The airplane is lifted by the greater air pressure below it.



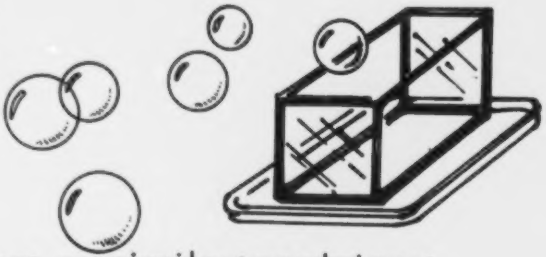
To keep a bubble aloft, the pressure must either be decreased above the bubble or increased below it.

Bernoulli:

Daniel Bernoulli (1700-1782), son of John Bernoulli, was a member of a famous family of Swiss mathematicians and scientists. At the age of 25 he began teaching mathematics at the University of St. Petersburg in Russia. In 1733 he arrived at the University of Basel in Switzerland. There he first taught anatomy, followed by botany, philosophy, and physics. He is sometimes called the founder of mathematical physics.

Young Bernoulli once met a stranger while traveling and said, "I am Daniel Bernoulli." The stranger replied sarcastically, "And I am Isaac Newton." Bernoulli took great delight in this tribute to his reputation.

RIDING ON AIR



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Name

Materials:
- plastic aquarium or similar container
- cafeteria tray or cookie sheet
- matches
- graduated cylinder or measuring cup, optional
- soap solution and bubble tool
- fresh vinegar, about 1 liter (4 cups)
- baking soda, about 350ml (1½ cups)

(use about 3 parts vinegar to 1 part baking soda)

Procedure:

1. Spread the baking soda in the bottom of the aquarium and then place it on the tray or cookie sheet.
2. Measure the vinegar and then pour it into the container. The tray will catch any foam that spills over the side.
3. Light a match and slowly lower it into the container to find the level of the carbon dioxide. The flame will be extinguished.
4. Quickly blow bubbles so that some land inside the aquarium but do not touch its walls.

What do you observe ?

____

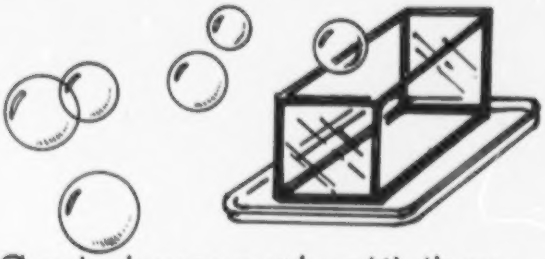
____

Why do think this happens ?

____

____

RIDING ON AIR FACTS



Soap bubbles in the air will float downward until they pop, unless they are kept aloft by the wind or an artificial draft. This happens because a bubble is denser than an equal amount of air, and gravity pulls it toward the earth.

The baking soda and vinegar mixture produces a chemical reaction and carbon dioxide gas is formed. The carbon dioxide, which is 1.53 times denser than the surrounding air, will stay in the container for a short time before it mixes with the air outside the container. The level where the layer of carbon dioxide meets the Earth's atmosphere in the container can be determined by seeing where a match flame is extinguished when it is lowered into the container. Bubbles will float at this level because carbon dioxide is denser than the bubbles and buoys them up, just like a ping pong ball is buoyed up and floats in water.

The Earth's atmosphere is comprised of a fairly uniform mixture of gases. About 78% of the atmosphere is nitrogen, 21% is oxygen, 1% is argon, and .03% is carbon dioxide. There are also traces of several other gases such as neon, helium, hydrogen, and methane.

It is interesting to note that breath-blown bubbles are slightly denser than bubbles formed by waving a bubble tool through the air. Breath-blown bubbles have a greater concentration of carbon dioxide than is present in the air because the oxygen people inhale is exchanged for an almost equal amount of carbon dioxide when the air is exhaled. Since carbon dioxide is a denser gas than the surrounding air, it makes breath-blown bubbles denser than air-filled bubbles.

LIQUID RAINBOWS

I. Topic Area
Soap film colors and interference

II. Introductory Statement
Students will find the color sequence which leads to the bursting of soap film via the comparison of a flat film and a hemisphere.

III. Math Skills
a. Sequencing

Science Processes
a. Predicting
b. Observing
c. Comparing
d. Collecting & recording data
e. Applying & generalizing

IV. Materials
3–5 straws and string/yarn per team
soap solution in containers
rags for cleanup
crayons

V. Key Question
How can you tell when soap film will pop?

VI. Background Information
Gravity works on the molecules in a soap film stretching across a frame that is hung vertically. It pulls the molecules down toward the bottom of the frame, making the film thicker at the bottom and thinner on the top. The cohesion between the water molecules in the soap film keeps the film together until it is too thin, at which point it pops. Because of the way light reflects off of the soap film, different colors appear on the film in bands or stripes. The colored stripes leading up to the top, or thinnest film, show the order leading to the pop. The last several are:

GREEN → BLUE → MAGENTA →
YELLOW → WHITE →
WHITE WITH SPOTS → BLACK → *POP!!*

The color pattern in hemispheres is the same. Because of the three-dimensional shape, the color rings are circular. Thinning occurs at the top first.

The full scientific color sequence and the reasons for it are explained in the fact sheet, "Bubble Colors". This is included as teacher background since the subject of interference is normally introduced in high school physics classes. Share with students at your discretion.

VII. Management Suggestions
1. Students should work in pairs. They can use one desk for soap film work and the other desk for recording.
2. Each activity sheet will take 50 minutes or more. If time is limited, one activity sheet is sufficient. The classic method uses the vertical frame, but colors are more easily visible in hemispheres.
3. The vertical frame can be built in several ways. Two straws cut in half or four whole straws tied together with string can be used to form a square or rectangle. Colors are generally easier to see with larger frames but it is harder to obtain a soap film with them. Triangular frames will also work.
4. Finding an angle to view the colors takes some experimentation. A black or dark background and a direct light source overhead are helpful. Use black construction paper underneath if the table surface is not dark.

VIII. Procedure
What the Teacher will do:
1. Introduce the key question. Students may have already noticed colors in previous activities and guess that the colors might provide the answer.

What the Students will do:
2. Construct a straw frame using string or yarn.
3. Follow the directions on the first activity sheet.

What the Teacher will do:
4. Have the class compare results and encourage rechecking if there are major disagreements. The use of pencils allows for incorrect results to be changed, leaving no record of "mistakes". When the sequence is confirmed, it should be colored.

What the Students will do:
5. Predict how the vertical frame color sequence will compare to that of the hemisphere.
6. Follow the directions on the second activity sheet.

What the Teacher will do:
7. Lead the class comparison of results.

What the Students will do:
8. Discuss and answer the questions at the bottom of the page.

IX. Discussion Questions
1. Where is the soap film thinning most rapidly? (at the top, in both the vertical frame and the hemisphere)
2. What pattern did you discover as the soap film became thinner and finally popped? (green-blue-magenta-yellow-white-white with spots-black-pop!)

3. How much of the area was covered with black film before it popped? Would this change if we used a different amount of soap or changed the solution in some other way? (At least one variable, adding glycerin, tends to allow a greater area of black film for a longer period of time. Experiment with others.)
4. How do the results with the flat film and the hemisphere compare? (They are the same.)
5. What would you predict about the color pattern of a flat film held parallel to the floor? of a bubble?
6. Where do the colors come from? (reflected white light from the sun or a lamp)

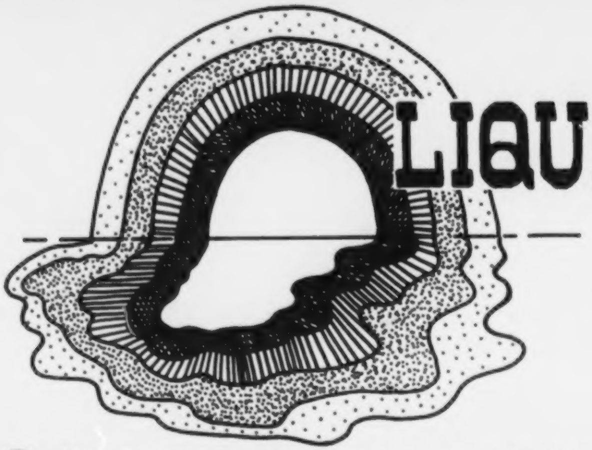
X. Extended Activities

1. Follow up the predictions at the bottom of the second activity sheet by testing them.
2. Add food coloring to the soap solution and observe soap films, bubbles, and color patterns. Does it make a difference?
3. Experiment with soap solution variables to broaden the area of black film before it pops.

XI. Curriculum Coordinates

Bubble Collage Art:
Make a thin mixture each of red, blue, and yellow poster paint with soap added. Blow bubbles with a straw and then bring a white sheet of paper down over them. The "pop" will leave a mark on the paper. Continue to complete a collage using the three colors.

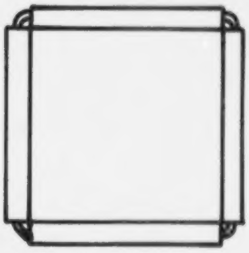
Names ______________________
____



LIQUID RAINBOWS

How can you tell when soap film will pop?

① Dip a straw frame in soap solution and hold vertically. On scratch paper, record the colors you observe until the pop. Where is the soap film thinning most rapidly?



____

Keep a close eye on this part.

Check and recheck your results. With a pencil, record your tested color sequence on the left. After class comparisons, color in the rectangle as far as possible.

COLOR NAMES

!! POP!!

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____
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SOAP FILM COLOR PATTERNS
VERTICAL FRAME

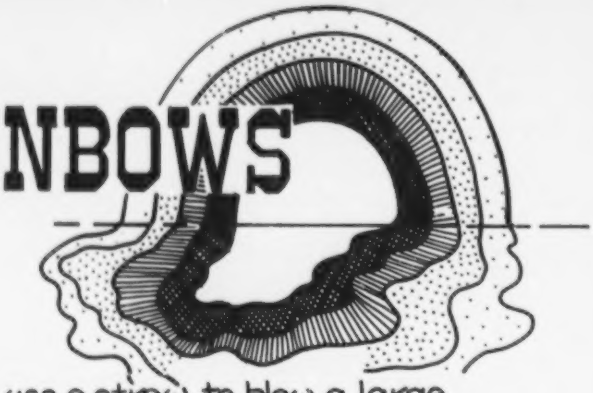
Brenda Howsepian

____

____

Names

LIQUID RAINBOWS



How will the color pattern of a hemisphere compare with that of a vertical frame ?

____

② Wet a dark, flat surface and use a straw to blow a large hemisphere. On scratch paper, record the colors until the pop. Where is the soap thinning most rapidly?

______________________________ Watch this part.

Check and recheck your results. On the left, record your tested color pattern with a pencil. After class comparisons, color the hemisphere.

COLOR NAMES

!!POP!!

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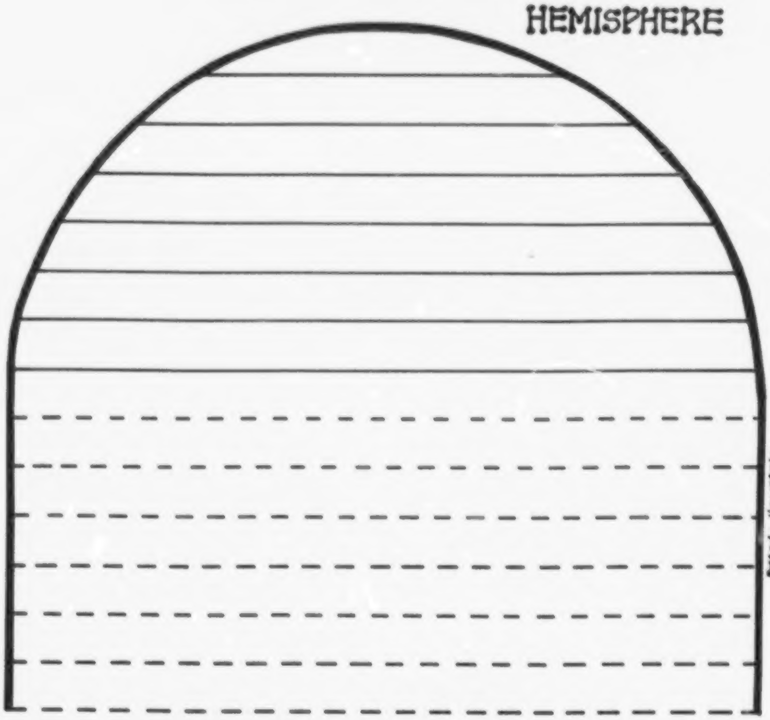
SOAP FILM COLOR PATTERN



How do these results of the flat film and the hemisphere compare?

____

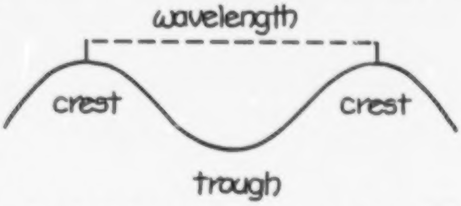
What would you predict about the color pattern of a flat film held parallel to the floor? ______________________________ of a bubble? ______________________

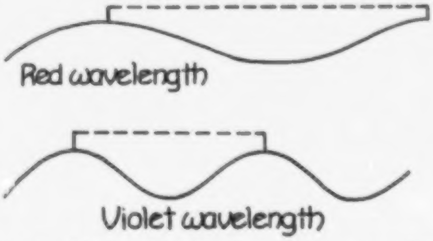
BUBBLE COLORS

What color is a soap bubble ? It is actually a rainbow of changing colors in the white light of the sun or a lamp. A prism breaks up light into its separate colors. With soap film, however, a color is removed from the light and all the remaining colors combine and reflect off the surface. The colors you see at any one time depend on the film's thickness.

LIGHT WAVES

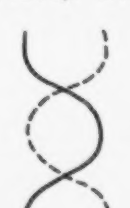
In one second, light can travel 7½ times around the earth. This is about 300,000 kilometers or 186,000 miles per second. In water, light travels three-fourths as fast as in air. Do you think you will notice the slower speed ?



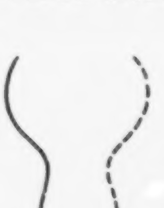


Light travels in waves. The crests look like hills and troughs like valleys. Each color has a different wavelength, the distance between two wavecrests. Red has the longest wavelength, 10.6 millionths of a centimeter (27 millionths of an inch). It would take about 14,600 red wavelengths end to end to make a line one centimeter long in the air (37,000 for an inch). The color red is followed by yellow, green, blue, and violet. Violet, the shortest, is 6.7 millionths of a centimeter long (17 millionths of an inch). Almost 23,200 wavelengths would be needed to make a one centimeter line in air (59,000 for an inch). All colors have shorter wavelengths in water.

Most of the light shining on a bubble passes right through; only 8% of it is reflected. Light waves are reflected from both the inner and outer surfaces of the soap film. The crests become troughs and the troughs become crests. This is similar to wiggling a rope tied to a chair leg. The waves are reversed on the return trip.

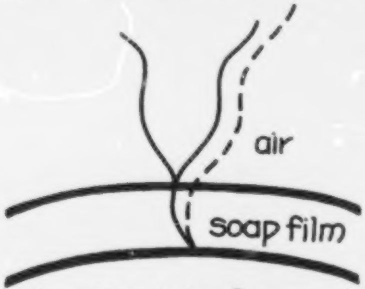


Reversing rope waves

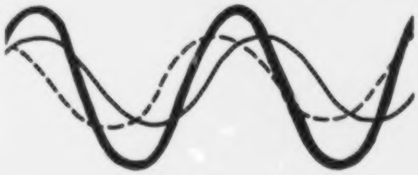


Reversing light waves

Other light waves travel through the liquid film, bounce off the inner surface, go through the film again, and then meet up with the waves reflecting from the outer surface. The light waves reflecting from the inside do not reverse.

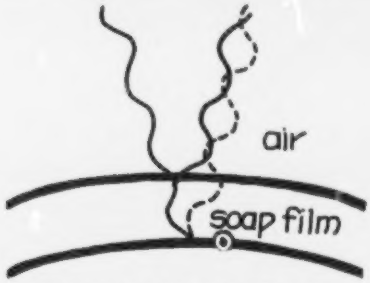


Constructive interference in soap film

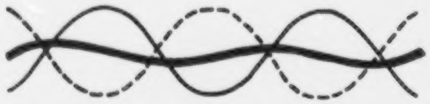


Effect

It is in the meeting of these two sets of reflecting light waves that interference occurs. When two waves meet and their crests match, the waves strengthen each other producing a strong, bright color. This is known as constructive interference.



Destructive interference in soap film.



Effect

If two waves meet crest to trough, they cancel each other and have little or no effect. In this process of destructive interference, the cancelled color is then subtracted from the rainbow that makes up white light. The remaining colors combine to form its complimentary color which is then reflected off the soap film. For example, if blue waves cancelled each other, the remaining red and green colors would combine to form yellow. Yellow? Yes, the results of these color combinations will not be the same as those found when mixing paint.

COLOR SUBTRACTED	COMPLIMENTARY COLOR
red	blue-green
yellow	blue
green	magenta
blue	yellow

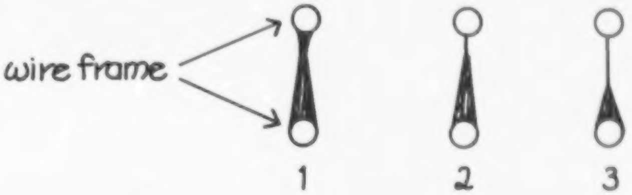
THROUGH THICK AND THIN

The thicknesses of the soap film determines which color wavelengths will interfere. The long, red wavelengths need a thicker bubble wall to get out of step than short, violet wavelengths. The red cancels when the film is the thickness of half the wavelength of red light. So, the colors change as the film becomes thinner.

When the bubble wall is thinner than the shortest wavelength of visible light (one-fourth of a blue wavelength), the two reflected waves meet crest to trough and all colors are cancelled. The bubble looks transparent or black because no light is being reflected. At this point, the soap film is only .25 millionths of a centimeter (1 millionth of an inch) thick. There are really two kinds of black film, the very thinnest is 1 ten millionth of a centimeter (1 four millionth of an inch) thick.

COLOR PATTERNS

If soap film or a soap bubble is hung vertically, the colors start to form horizontal stripes. As the film flows toward the bottom, the thinning area near the top shows bands of deeper and brighter colors. These bands become softer in color as the thickness increases. In a hemisphere or sphere, gravity is again responsible for draining film from the top. The bands form horizontal circles around the film. Each color band represents 1/250,000 of a centimeter (1/100,000 of an inch) change in soap film thickness.



Draining pattern of vertical soap film, side view

For vertical film, the color bands should appear from top to bottom as follows:

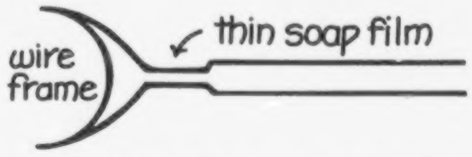
COLOR SEQUENCES

1	2	3	4	5
black	violet	purple	green	green
spotted white	blue	blue	red	pink
silver white	green	green		
yellow	yellow	red		
magenta	orange	blue-red		
	red			

You will not necessarily notice all these colors or label them in the same way. The reds and purples often swirl together and appear to be a magenta color.

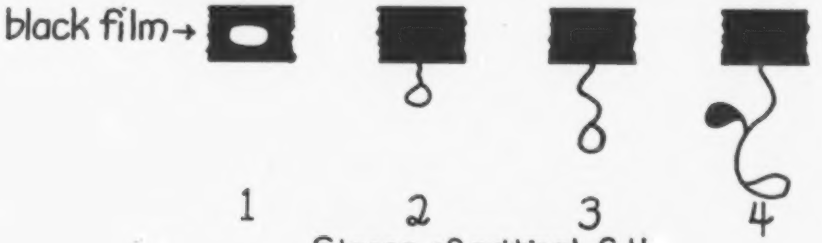
When observing hemispheres or bubbles, the colors will be reversed because you start with thick film and watch it thin. Generally you will see a series of greens and pinks, followed by repeated patterns of green, blue, magenta and yellow. The last five colors before the "pop", in descending order, are magenta, yellow, silvery white, white with black spots, and black.

What about the swirling colors at the borders of a soap film? The film is thinner close to the edges than in the central area. Because of the pressure differences, the thicker film is drawn to the border and the thinner film is pulled toward the center. Scientists call this marginal regeneration.



Marginal regeneration, side view

As a black region forms, sometimes thin rivers of black will flow into the colored area of the film. Critical fall, as it is known, usually happens with soap solutions having more than 4% of surfactants. Surfactants are ingredients which act on the surface of a liquid.



Stages of critical fall

What causes critical fall? First, an island of thicker, silver-white film is caught in the thinner black film. As the black area continues to grow, the island shrinks, becoming thicker and heavier. Gravity finally makes it fall into the colored film trailed by a stream of black. Branches form as the black area expands. The black pathways, being lighter in weight, rise and form small lakes.

SOAP COOKBOOK

I. Topic Area

Comparing bubble solutions

II. Introductory Statement

Students will learn how to make direct comparisons of the ingredients in soap recipes and how to change their amounts.

III. Math Skills / Science Processes

Math Skills	Science Processes
a. Figuring proportions	a. Comparing

IV. Materials

Calculators

V. Key Question

How can the amounts of the ingredients in these soap solution recipes be compared?

VI. Background Information

A scientist must be able to make comparisons between ingredients in formulas or recipes. To do this, a common standard must be found. In this investigation, 100 parts of water is the standard. It was chosen because it relates well to percentages. The student activity sheet contains actual recipes from several bubble sources.

It is also important for a scientist to make the right amount of solution for a particular purpose. Often this means altering the amounts in the original recipe, as they may be too large or small.

Figuring Proportions:

(a) Set up the ratios and proportion for solution A.
(b) Cross multiply 100 by 120 and 960 by x.
(c) To isolate x, divide both sides by 960.
(d) Divide, using a calculator and the result is 12.5. In solution A, if you have 100 parts of water, you would have 12.5 parts of soap.

(a) $\frac{100}{960} = \frac{x}{120}$ (b) $960x = 12{,}000$

(c) $x = \frac{12{,}000}{960}$ (d) $x = 12.5$

Converting proportions:

To change the 100 parts of water into a recipe with 250 ml water set up a proportion to find the amount of soap. Calculate x as above. Then make another proportion for the glycerin.

$\frac{250}{100} = \frac{x}{8}$ $\frac{250}{100} = \frac{x}{2}$

VII. Management Suggestions

1. Groups of 2-3 are suggested.
2. This activity will take 30 minutes or more, depending on student background in ratios and proportions.

VIII. Procedure

The teacher should review ratios and proportions as needed.

What the Students Will Do:

1. Figure the proportions for each solution recipe.
2. Discuss and compare recipes.
3. Convert the recipe on the second page into the varying amounts listed.

IX. Discussion Questions

1. Which solution has more than 50% soap? (E)
2. Which solution has the weakest concentration of soap? (D)
3. How does the use of glycerin vary? (Some recipes use more of it than soap while, in others, it is of minor importance.)

X. Extended Activities

1. Which is the best solution? (That answer can only be found through testing and it depends on the purpose of the solution. Is it for long-lasting bubbles? giant bubbles? something else? See the activity, "What's the Best Solution?" to make a plan for finding the answer.)

XI. Curriculum Coordinates

Home Economics:

Convert a food recipe into a smaller or larger amount. The premise might be cooking for two people or for a crowd at a holiday meal. Choose one with whole numbers unless the class can handle multiplication and division of fractions. Make the recipe and eat it.

Name______________

SOAP COOKBOOK

Often a scientist needs a direct way of comparing the ingredients of one solution with those in another. In the following, this is achieved by using 100 parts of water as the standard. How many parts of soap and glycerin are used in each?

SOLUTION	WATER	SOAP	GLYCERIN	FIGURING PROPORTIONS	
				SOAP	GLYCERIN
A	100 parts			$\frac{100}{960} = \frac{x}{120}$	none
	960 ml	120 ml	none		
B	100 parts			___ = ___	___ = ___
	240 ml	80 ml	240 ml		
C	100 parts			___ = ___	___ = ___
	480 ml	96 ml	96 ml		
D	100 parts			___ = ___	___ = ___
	3,800 ml	175 ml	15 ml		
E	100 parts			___ = ___	___ = ___
	720 ml	576 ml	124 ml		

SOAP COOKBOOK

____
Name

How many milliliters of soap and glycerin are needed for each of these recipes?

100 parts water
8 parts soap
2 parts glycerin

100 ml water

____

____

250 ml water

____

____

600 ml water

____

____

750 ml water

____

____

WHAT'S THE BEST SOLUTION?

I. Topic Area
Long-lasting bubbles

II. Introductory Statement
Students will identify the variables that determine the effectiveness of soap solution in extending the life of bubbles. They will isolate one variable and devise a way to test it to determine the optimum solution.

III. Math Skills
a. Timing
b. Finding averages

Science Processes
a. Making & testing hypotheses
b. Controlling variables
c. Collecting & recording data
d. Applying & generalizing

Additional skills or processes are dependent on the testing procedure the students devise.

IV. Materials
soap
blowing tools — straws or circular wands
watch or clock with second hand

Other materials are dependent on the testing procedure the students devise.

V. Key Question
What is the best solution for creating long-lasting bubbles?

VI. Background Information

Variables to consider are the temperature of the water, hard vs. soft water, the kind of soap, the amount of soap, kinds of additives, and the amount of additives. This investigation deals only with the components of the solution. Attention to the environment is given in "Don't Burst My Bubble".

Water Temperature

Cold water is supposed to be good for bubbles. Your results may or may not bear this out. Questions to consider when setting up the experiment: How hot? How cold? Test a lukewarm temperature? How are the temperatures going to be kept stable?

Hard vs. Soft Water

Water which flows through rocks or soil picks up minerals such as limestone and gypsum. The water is *hard*. Pure water is *soft*. Communities have different kinds of water, dependent on water treatment facilities and geography.

The effects of hard water on soap are explained below. Though it is helpful to understand the chemistry between hard water and soap, the amount of suds produced is not necessarily related to a solution's value in creating bubbles.

Hard water makes it difficult for suds to form, at least with bar soap. The calcium (in limestone or gypsum), magnesium, or iron in hard water have atoms which can replace the sodium atoms of soap molecule heads, changing the whole molecule. See "It's a Small World" for details on the structure of soap molecules.

The mineral atoms each have two positive charges. Since a sodium atom has only one charge, each mineral atom can replace two sodium atoms and make a molecule with one head and two tails. These new molecules stick together below the water's surface. They do not form clusters and they cannot form films on the surface.

In contrast, the head of detergent molecules are constructed so that the sodium atoms are not replaced by calcium, magnesium, or iron atoms. A detergent can work, even in hard water. But does it work as well? All indications point to soft water as being more favorable for bubbles.

The challenge is to set up an experiment with significant results. Remember, it is not the amount of suds which counts, but what helps a bubble live longest.

Water samples should include the local tap water, distilled or rain water (soft), and hard water. Hard water can be made by dissolving either epsom salts (magnesium sulfate) or plaster of paris (gypsum) in water.

See "Shake, Foam and Suds" in the AIMS book, *Water Precious Water, Book A* for a related activity.

Kind of Soap

Those who have worked with a variety of soaps usually recommend Dawn or Joy dishwashing liquid as the best for making bubbles. Soaps with lemon added also do well. Compare brands in different price ranges. include a generic brand and one of those mentioned above.

An interesting extension might be to compare your results to tests on soap cleaning effectiveness reported every few years in *Consumer Reports* magazine. Is the soap that helps create long-lasting bubbles also the one that does a good job of cleaning dishes?

Another possibility is to explore the differences between bar soap, laundry flakes or powders, and liquid detergents. Although the soap molecules have similar characteristics, they behave somewhat differently.

See "Bubble Busters" and "Little Bubble Busters" in the AIMS book, *Water Precious Water, Book A* for structured investigations of this variable.

Amount of Soap

What is the best ratio of soap to water? 1 to 10? 2 to 10? 3 to 10? 4 to 10? 5 to 10? See "Soap Solution Recipes" for ratios others have used. The test should be set up with evenly spaced increments.

Additives

Glycerin and sugar products are both helpful for bubble longevity. Glycerin is available in drugstores. Sugar comes in various forms: granulated sugar, lemon juice (fructose), corn syrup, and gelatin.

Students should be encouraged to try whatever else they think will work. Vinegar or rubbing alcohol might yield interesting results.

VII. Management Suggestions

1. Organize the class into groups of four.
2. This activity is open-ended. Student groups can all explore the same variable, the class may want to take on all the variables over a period of time, or each student group may work on a different variable.
3. The teacher should act as a facilitator of the scientific process, giving only the minimum amount of information necessary to formulate a plan. That information is essential for some variables.

VIII. Procedure

What the Teacher will do:

1. Ask the key question and give student groups time to brainstorm the possible variables.
2. Discuss these variables. Student groups and/or the teacher will determine the assignment of variables to be tested within the class.
3. Move among groups, giving help and information as needed.

What the Student groups will do:

4. Discuss and record a plan for testing one variable on the group planning sheet.
5. Conduct their test.
6. Evaluate the results and revise the test if necessary.
7. Use tables, graphs, or other means to display the results. A blank table is included. Oral reports are another option.

IX. Discussion Questions

1. Are the differences in your results significant enough to form a conclusion?
2. Does the experiment need to be revised and tried again? (This is a common scientific practice.)
3. What's the best solution?

X. Extended Activities

Put the results of testing the variables together into one grand solution. How long do the bubbles last?

XI. Curriculum Coordinates

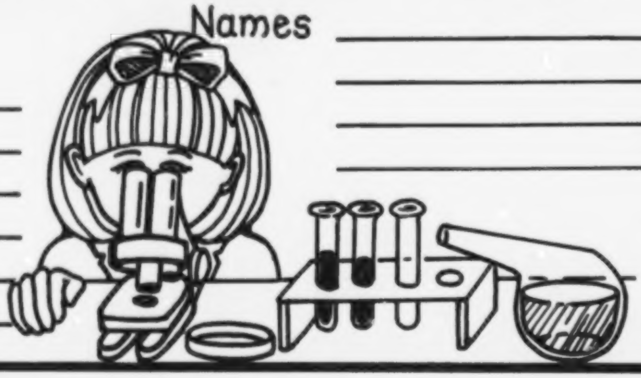
Language Arts:

Write a story for the school newspaper about the class experiments and results.

WHAT'S THE BEST SOLUTION ?

Variables

Names



GROUP PLANNING SHEET

Variable to be tested :

Hypothesis :

Materials needed :

How will other variables be controlled ?

Describe your testing procedure :

How will you show the results ?

B. Housepian

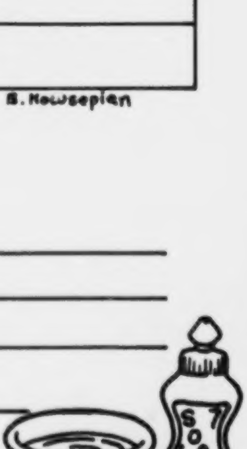
WHAT'S THE BEST SOLUTION ?

Names ______________________
____
____
____

TRIAL					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Total					
Average					

B. Hovsepian

Conclusion: ____
____
____
____



DON'T BURST MY BUBBLE!

I. Topic Area
Bubble environments

II. Introductory Statement
Students will learn that environment is one factor affecting bubble longevity and that wet conditions are most favorable.

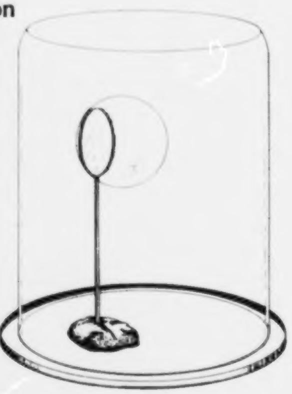
III. Math Skills
a. Sequencing
b. Estimating
c. Timing
d. Finding averages

Science Processes
a. Predicting
b. Controlling variables
c. Observing
d. Collecting & recording data
e. Generalizing

IV. Materials
1 or more sets per class:
soap solution
bubble wand
digital stopwatch or watch with second hand
round plate (saucer, pie plate, paper plate. . .)
glass quart jar or other large, clear container
thumb-size lump of clay
paper towels

V. Key Question
In which environment will a bubble last longest?

VI. Background Information



This investigation isolates the variable of environment. Other variables such as soap solution and bubble size must be kept uniform so that only the effect of environment is tested.

Dry air will evaporate the water in a bubble, causing it to pop. Small particles of dust and air movement from heaters and air conditioners are also bubble enemies. Moist air will slow the evaporation of water from the bubble, keeping it intact for a longer time. Observe changes in the wet jar bubble. The liquid film will slowly flow to the bottom of the bubble and the film will become increasingly thin at the top, almost invisible.

No matter how the bubble is positioned, it will still drain from the top because of gravity. The upright position suggested for the bubbles in this activity should not change the results. Feel free to experiment with a different position but use it consistently throughout the investigation.

The known record for keeping a bubble alive belongs to Eiffel Plasterer, a former physics teacher. With a special solution (which remains a family secret) and a closed jar, he kept a 4-inch bubble alive for 340 days! It never popped, but slowly lost air until it disappeared. This is all the more remarkable because it was breath-blown; carbon dioxide is not kind to bubbles. See "Bubble Personalities" for more about Mr. Plasterer.

Most likely, your wet jar bubbles will last several hours. However, if you set a new record or have some unusual results, please write the AIMS Education Foundation.

VII. Management Suggestions
1. Students should probably record time in seconds for the open air and dry jar trials. Minutes should be used to measure wet jar bubbles. For example, 2 hours and 37 minutes would be recorded as 157 minutes [(2 x 60) + 37]. This method is necessary to find the averages. The average can then be converted back to hours and minutes. There is room in the table to record both the initial reading and its converted form, if desired. Don't discuss what to use with the class until the demonstration is completed.
2. Divide the class into groups of 3 or 4. Assign jobs within each group — bubble blower, timer, jar coverer, recorder/reporter. Each group is responsible for one trial, with a minimum of five trials for the class.
3. After the teacher demonstration, it is possible to have trials running throughout a single day; however, one or two a day for a week may be more manageable. If more than one set of materials is available, trials can be run simultaneously.
4. *Part One:* Introducing the investigation, writing predictions, and demonstrating procedures will take 30–45 minutes, longer if you watch the wet jar bubble.
   Part Two: Group trials can be started the same day or may be done during the following days. Each group will need about 30 minutes to test the three environments, after which one or two persons will be needed to watch the wet jar bubble. Change the "guard" periodically because the wet jar trial will generally take from 30 minutes to several hours.
   Part Three: After all trials are completed, another 30 minute period will be needed for computations and discussion.
5. Do this activity indoors in a place where the bubble won't be disturbed by strong air currents or vibrations.

Don't Burst My Bubble, continued

VIII. Procedure

1. Ask the key question.
2. Students will predict the best bubble environment by ranking environments from longest to shortest. Time estimates will be made later.
3. Demonstrate the procedures for using the jar environments and picking a bubble size that will fit in the jar easily. Time all trials from the blow to the burst, or other agreed upon criteria. The demonstration times can be considered Trial 1 or not recorded at all.

   Open Air: Have students write a time estimate next to their open air ranking. Put a lump of clay in the center of the plate. Blow a bubble, capture it with the bubble wand, and anchor the wand upright in the clay.

   Dry Jar: Wipe any moisture from the plate and clay. Have students write a time estimate next to their dry jar ranking. Proceed as in open air, but quickly cover with a dry jar. The dry jar is different from open air because it protects against air currents.

   Wet Jar: Have students write a time estimate. Wash the inside of the jar and the plate with soap solution or water. Leave a shallow layer of soap solution or water in the plate. This will help form a seal against the dry outside air and keep the environment humid. Follow the steps in the preceding trials. Cover quickly. Be prepared to wait awhile for the pop or plan accordingly.
4. Schedule group trials.
5. Students will:
   a. Each conduct a group trial and record the results.
   b. Report group results so the entire class can complete the table.
   c. Find the totals and averages for each environment and rank the results.
6. The teacher will lead a concluding discussion.

IX. Discussion Questions

1. Before passing out the activity sheet ask, "How do you think we can make a bubble last longer?" (add more soap, add other things, etc.)
2. Why did you rank your environments in that order? (Students should have a reason, or hypothesis, for choosing their ranking.)
3. How does the dry jar environment differ from open air? (protects the bubble from air currents)
4. What changes did you notice in the wet jar bubble? (Liquid flowed toward the bottom of the bubble and the film became increasingly thin, particularly on top. Sometimes it becomes almost invisible. At this point, it has gone through the color sequence discovered in "Liquid Rainbows" and the film is now black.)
5. If the trial times varied widely for a certain environment, why? (the bubble might have been picked and covered too slowly, bubble sizes weren't uniform, etc. The more trials that are done, the more accurate the results.)
6. What is the class record for keeping a bubble alive?
7. What are your conclusions? (There may or may not be a significant difference between the open air and dry jar results. Neither do much to delay evaporation. The wet jar environment is best because moisture keeps the bubble from drying out quickly.)
8. What kind of weather would be good for making long-lasting bubbles? (little or no wind and high humidity, maybe after rain or snow)

X. Extended Activities

Would open air bubbles last longer on a rainy or humid day? Time and compare.

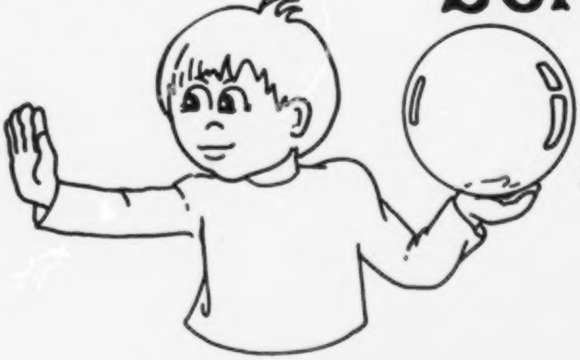
XI. Curriculum Coordinates

Language Arts:

1. Brainstorm words associated with bubbles. Write a descriptive or direction paragraph about blowing bubbles or this investigation.
2. Discuss the word "environment" and then use its letters to form as many new words as possible.
3. Write about your results to the AIMS Education Foundation, P. O. Box 8120, Fresno, CA 93747.

Name ______________________

DON'T BURST MY BUBBLE!



In which environment will a bubble last longest ?

Rank from longest to shortest.

	PREDICT		ACTUAL	
	ENVIRONMENT	TIME	ENVIRONMENT	TIME
1				
2				
3				

TRIAL	OPEN AIR	DRY JAR	WET JAR
1			
2			
3			
4			
5			
6			
7			
8			
TOTAL			
AVERAGE			

SWELL HEMISPHERES

I. Topic Area

Lung capacity

II. Introductory Statement

Students will compare their lung capacity with others by blowing and finding the volume of soap film hemispheres.

III. Math Skills / Science Processes

Math Skills	Science Processes
a. Finding volume	a. Predicting
b. Finding averages	b. Measuring & comparing
c. Sequencing	c. Collecting & recording data

IV. Materials

1 straw per person
soap solution
rulers
calculators
cookie sheets or cafeteria trays, optional

V. Key Question

Who has the largest lung capacity?

VI. Background Information

To blow a hemisphere, wet a large surface area with soap solution, hold a straw dipped in solution close to the surface at an angle, and blow.

When a hemisphere pops, it leaves a soap film trace of its circumference. From this, the diameter, and thus the radius, can be determined. Sometimes a soap film will pop before it has stabilized; blowing may cause it to be temporarily distorted into an oval shape. If this occurs, the sample is not valid.

The formula for finding the volume of a *sphere* is $V = 4/3 \pi r^3$. The volume of half of a sphere, or *hemisphere*, is found by the formula, $V = 2/3 \pi r^3$ It must first be determined whether the soap films blown on a surface are true hemispheres. The height of the hemisphere should be the same as the radius across the bottom because the height is also a radius generating from the center of the circle.

VII. Management Suggestions

1. Decide where the hemispheres will be blown — flat desks, large tables, on trays or cookie sheets, etc. It may be a good way to clean the classroom furniture.
2. After demonstrating the procedure for blowing a hemisphere, give students time to practice and experiment. Let them discover that slow, steady blowing works best. Do this *before* introducing the investigation.
3. In order to insert the rulers through the hemisphere, they must be wet, preferably with soap solution. Even then, the hemispheres may pop. In that event, have students measure the diameter in order to determine the radius. Shall they measure to the nearest centimeter, half centimeter, or millimeter?
4. Set up student groups of 3 to 4.
5. This activity will take at least 45 minutes. Illustrating the results will take a second session of about 30 minutes.

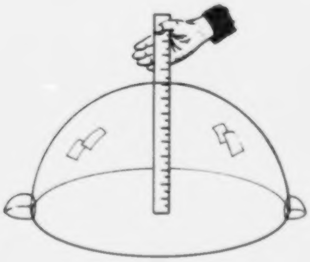
VIII. Procedure

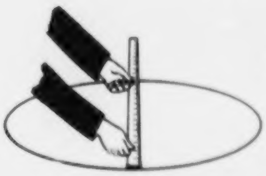
What the Students will do:

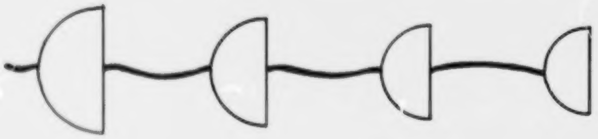
1. Predict, by sequencing from most to least, the lung capacity of those in their group.
2. Compare the radius of the circle made by soap film hemispheres to the dome's height to determine if they are true hemispheres.
3. Prepare to use the formula by figuring $2/3 \times \pi$, preferably in decimal form for use with a calculator. ($.67 \times 3.14 = 2.1038$ or $.667 \times 3.1416 = 2.095$. Either can be rounded to 2.1.)
4. Each blow four hemispheres using only one breath each time, measure the radius by height or diameter, and use the formula $V = 2.1 \times r^3$ to find the volume and average volume.
5. Rank the actual lung capacities for each group member on the top of the page.

What the teacher will do:

6. Challenge student groups to find a way to illustrate their results. Two suggestions: a) a bar graph b) paper cutouts of average hemispheres mounted on yarn according to ranking. Find the average radius and use a compass.





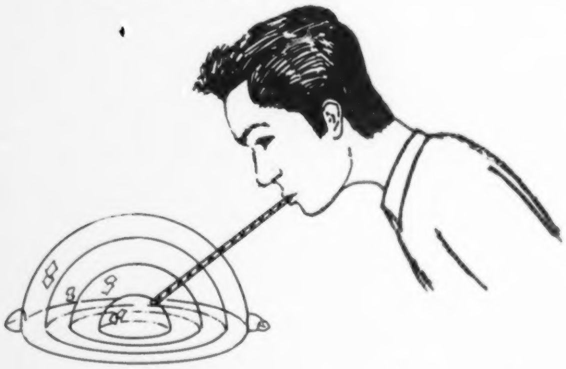


IX. Discussion Questions

1. Why did you set up your prediction the way you did? (There should be some kind of hypothesis governing their rankings. A common one might be the size of the students; the taller or larger the student, the larger their lung capacity.)
2. Do soap films form true hemispheres? (Yes. The height of the dome and the radius of the circle it forms are the same or very similar.)
3. Why do you think your results turned out the way they did? (Size and/or degree of physical conditioning may be factors.)

X. Extended Activities

1. Blow hemispheres within hemispheres. How many concentric hemispheres can be blown inside each other?

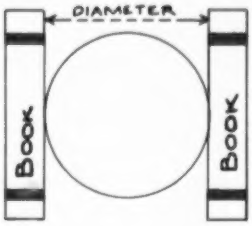


2. Try to blow the largest hemisphere possible without any restrictions. Take as many breaths as you want, have more than one person blow on the hemisphere at the same time, try different blowing tools such as several soup cans open on both sides and taped together.

XI. Curriculum Coordinates

P.E.:

1. If involved in an aerobic conditioning program, do a before and after check on lung capacities using soap film hemispheres. Does aerobics improve the general function of the lungs or their actual capacity to hold air?
2. Compare the volumes of a volleyball, tennis ball, ping pong ball, etc. using the formula, $V = 4/3 \pi r^3$ First devise a means to find the radius. Two straight objects such as books, rulers, or desks placed parallel on either side of the circumference will give a measurable diameter. Calipers will also work.



SWELL HEMISPHERES

Name______________

Who has the largest lung capacity?

	PREDICT	ACTUAL
most		
↓		
least		

① Blow a hemisphere using only one breath. It's height is______cm; it's radius is_____cm. Is it a true hemisphere ?

② The formula for the volume of a hemisphere is

$$V = {}^2\!/_3\, \pi r^3$$

Using decimals, what is $^2/_3 \times \pi$?

____

③ Find the average volume of your hemispheres based on four samples.

____

name

	RADIUS	VOLUME
1		
2		
3		
4		
AVERAGE VOLUME		

____

name

	RADIUS	VOLUME
1		
2		
3		
4		
AVERAGE VOLUME		

____

name

	RADIUS	VOLUME
1		
2		
3		
4		
AVERAGE VOLUME		

____

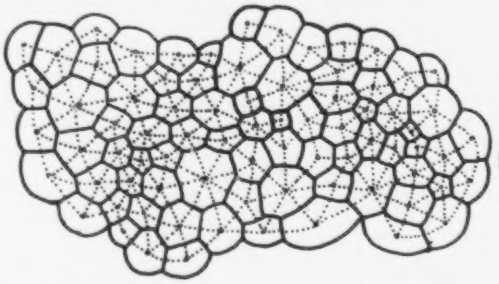
name

	RADIUS	VOLUME
1		
2		
3		
4		
AVERAGE VOLUME		

NATURE'S PATTERNS

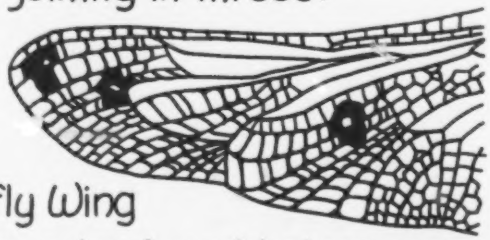
Soap bubbles are a model for the most common geometric pattern in nature. Triangulation, where three lines join at 120 degree angles, is repeated in a wide variety of forms in nature - physical, biological, and chemical. It is most often the result of matter trying to minimize its area.

Two Dimensions

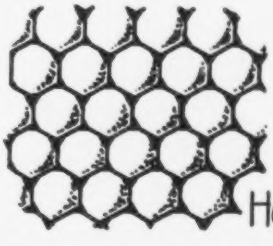


Bubble Cluster

In two-dimensional objects, these triple junctions create a hexagonal pattern. When uniform bubbles are blown under glass, the cylinders are squeezed into hexagons, their centers joining in threes.

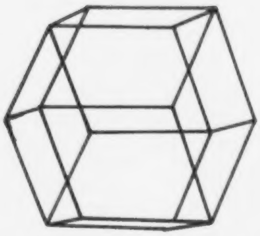


Dragonfly Wing

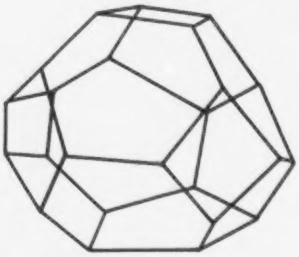


Bees' Honeycomb

The animal world gives many examples of triangulation and hexagonal patterns. The lines of the shell of a box turtle meet at 120 degree angles. The same is true of the cells in a dragonfly's wings where the ribs are wide enough apart to allow several rows of cells to come in contact with each other. Bees instinctively form hexagonal honeycombs. Each honeycomb cell contains the greatest amount of honey with the least amount of beeswax. The same triangular pattern can be seen in coral, in insect eyes, in alveoli in the human lung, and on the skin of reptiles and giraffes.



Rhombic Dodecahedron

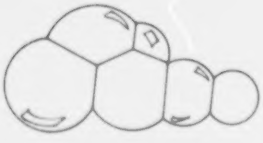


Tetrakaidekahedron

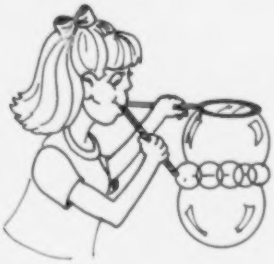
Lord Kelvin (1824-1904), a Scottish mathematician, first proposed a truncated octahedron (6 square faces and 8 regular hexagonal faces) with 1% less surface area for a given volume than the rhombic dodecahedron. Later he found a 14-sided figure, called a tetrakaidekahedron, with slightly less surface area than the truncated octahedron; its angles are close to 109 degrees. However, this mathematically ideal shape is rarely found in nature because nature seldom divides things equally.

In 1946, Edwin Matzke found that pentagonal faces are more common to the three-dimensional figures. Bubbles, when packed together, form several kinds of polyhedrons including rhombic dodecahedrons and truncated octahedrons. Bubble froth does not have uniform shapes, but the polyhedrons in it have an average of 13 to 14 faces (each with 5 to 6 edges) and 22 to 23 corners.

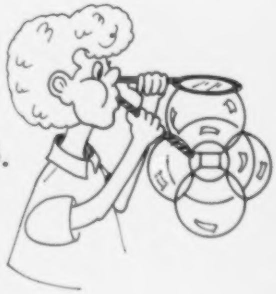
You can observe this by putting a small amount of soap solution in a clear quart jar and swirling it around to wet the sides. Then use a straw to blow a lot of bubbles. Study the intersections, the faces, and the designs. It is a model for many of the patterns in nature.



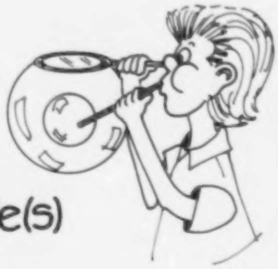
BUBBLE CHALLENGES



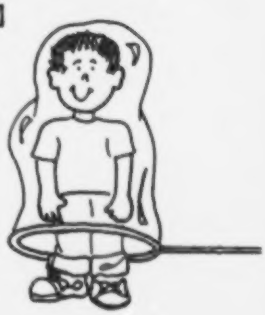
1. Freeze a bubble.
2. Put dry ice into a large, open, cubical container, let it sit a little while, and then blow bubbles over it. How does carbon dioxide affect bubbles?
3. Invent a bubble making machine.
4. Make a chain of bubbles hanging from a wand or tin can.



5. Hang two joined bubbles from a wand and use a straw to surround it with a belt of smaller bubbles.
6. Bring two bubbles together to make one bubble.
7. Make a square bubble. Join two bubbles and build four more around the middle. Insert a wet straw in the middle to blow a cube.



8. Bounce a bubble on a soap film trampoline.
9. Blow a bubble inside another one.
10. String a 3-bubble chain between wands or your hands. Move both in a circular motion. Which bubble(s) spin?



11. Make large hoops for giant bubbles and tubes. Use a coat hanger or similar wire from the hardware store. Wrap the frame completely in cotton string. Don't forget to make a handle. Try to enclose a person in a bubble tube.

BIG IDEAS

1. Bubbles like wet surfaces.
2. When free-floating bubbles stabilize, they will always form spheres.
3. Soap lessens the surface tension to one third of that of plain water.
4. Soap film pulls equally in all directions and covers the minimum area possible.
5. Soap molecules have heads which like water and tails which try to stick out of the water. This causes the change in the water's surface tension.
6. Bubbles between two rings form catenary curves and break at a distance of 1.325 times the radius of the rings.
7. Soap films can be used to determine the shortest connections between any number of points because they always form the minimum surface.
8. In 3-dimensional soap films, three (and only three) surfaces meet at 120 degree angles to form a line. Four lines meet at about 109 degree angles to form a point.
9. Small bubbles have greater air pressure than large ones. The sharper the curve, the greater the pressure.
10. The colors in soap film are caused by interference. From the color sequence, the pop of the film can be predicted, whether in 2-D or 3-D form. The final sequence is magenta, yellow, white, white with spots, black, pop!
11. Several variables determine the effectiveness of a soap solution in creating long-lasting bubbles: temperature of the water, hard vs. soft water, the kind and amount of soap, the kind and amount of additives.
12. Bubbles last longer in a wet, protected environment. Humidity retards evaporation.

GLOSSARY

atom - the smallest particle of an element that can exist alone or in combination

adhesion - attraction of unlike molecules to each other

catenary - the curve formed by a hanging chain

cohesion - attraction of like molecules to each other

compound - substance whose molecules are made up of two or more different types of atoms

covalent bond - a chemical bond within a molecule in which two electrons are shared by two atoms

elasticity - stretchability

hemisphere - half of a sphere

hydrogen bonding - the attraction of hydrogen atoms in one water molecule to the oxygen atoms in others

hydrophilic - likes water

hydrophobic - hates water

ionic bond - the chemical bond within a molecule in which electrons between two atoms are gained or lost

interference - the effect on meeting of two beams of light which results in neutralization (destructive) at some points and reinforcement (constructive) at others, producing changes in color

micelle - a cluster of soap molecules under the surface of water

minimum - least, smallest

polyhedron - many-sided figure

surface tension - the molecular forces which cause the surface of a to behave like an elastic skin continuously being pulled

surfactant - a substance which acts on the surface of a liquid

variable - something that is changeable

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